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Proceedings of the

GEOLOGISTS' ASSOCIATION

A PRELIMINARY SURVEY OF THE SARSEN AND PUDDINGSTONE BLOCKS OF THE CHILTERNS

By A. Morley Davies, D.Sc., F.G.S. and Arnold H. J. Baines, M.A.

[*Received* 15 *September* 1952]

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ABSTRACT.—Large boulders (not glacial erratics) of three kinds are found in the Chilterns: (1) Sarsens, evenly distributed, with two gaps; (2) Hertfordshire Puddingstones, extending from Hertfordshire into Buckinghamshire, as far as Chesham, with a few beyond overlapping the area of (3) Bradenham Puddingstones. Some Sarsens are pot-holed. Evidence is given of transport by human agency both in pre-historic or early historic and in modern times.

1. INTRODUCTION

THE field-work of this survey was started in the early summer of 1951 by the senior author, and on his incapacitation was taken up and extended by the junior author. Great assistance was also given by Mr. A. J. Arkell (Ballinger), Lady Barlow (Wendover), Mr. P. T. Carr (Farnham Common), Mrs. Davies, Rev. W. H. Davis (Little Missenden), Mr. Stratton Gurney (Amersham), Mr. J. T. Lloyd (Amersham), Mr. F. Lofts (The Swillett), Mr. L. J. Morison (Henley), Dr. K. P. Oakley (Amersham), Mr. R. T. Padget (Amersham), Mr. F. Pavry (Princes Risborough), Mr. C. O. Skilbeck (Bledlow), Mr. S. J. S. Smith (Bolter End), the Hon. S. Stonor (Stonor), Mr. A. Stratford (Chesham), Mrs. Treacher (Twyford), Mr. R. F. Turney (Chorleywood), Major R. H. Way (Gerrards Cross), Mr. F. West (Saunderton) and others. The list published by the late Dr. A. E. Salter in 1911 (see Bibliography) and the MS. records by the late J. H. Blake on 6-inch geological sheets have also been very helpful.

The area covered is mainly Buckinghamshire south of the Chalk scarp, but some extensions into the Vale of Aylesbury, south Oxfordshire and Hertfordshire have also been made. Defining a locality as a place for which a separate National Grid reference has been given, the number of localities recorded is over 250 in Buckinghamshire, 22 (not all verified) in Oxfordshire and 45 (not all verified) in Hertfordshire. Leaving out cases where the stones were too numerous to count, the number recorded at each locality varied from one to over 100, with an average of five.

2. THE THREE TYPES OF STONE

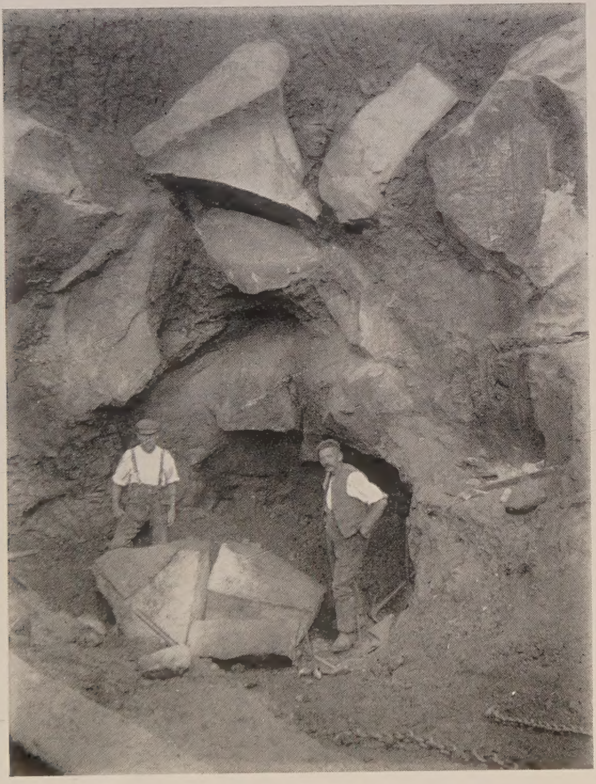
Three types of stone are included:

(1) *Sarsen, Greywether* or *Druid Sandstone*: hard siliceous sandstone without pebbles.

(2) *Hertfordshire Puddingstone* (referred to as HP): sarsen matrix closely packed with well-rounded pebbles, mostly about an inch in diameter, but often less (especially in the Latimer–Flaunden area) and occasionally up to two inches or more (especially near St. Albans); most commonly black, but often various shades of grey, occasionally brown or red. The black colour is in some confined to a thin surface skin, in others it extends throughout the pebble, and in the latter case there may be a thin light-tinted skin: there are many variations. A banded character, from alternations of different sized pebbles, is sometimes seen (as in the large blocks at Kingsbury Mill and Manor, St. Albans), or a few large pebbles may be scattered among the small.

(3) *Bradenham Puddingstone* (referred to as BP and known locally as pebble-stone): sarsen matrix with poorly-rounded irregular flints, occasionally as much as eight inches in length, brown and toughened.

Transitional forms between the three types are occasionally found, the pebbles usually dying away in a sarsen matrix. Such a transition from HP to sarsen is well shown in a large block at the rear of the National Provincial Bank at Chesham (Nat. Grid ref. 960.016), in which pebble-bands alternate with pure sarsen. A similar block, said to have been brought from the old gravel-pit at Mobwell (890.021), is a conspicuous feature on the village green of The Lee (900.043). Transitions from BP to sarsen are recorded from Hambleden, Bradenham, Stony Green, Lee Clump and Wendover. It is remarkable that Judd (1901) should have stated that 'there is no very striking resemblance between the cement of this (Hertfordshire) conglomerate and that of any of the Sarsens which I have examined'. Fresh microscopic examination seems desirable. Transition from one type of puddingstone to the other are rarer and need careful study. On Cholesbury Common (933.072) are two well-known large blocks—the larger (6 ft. long) being pure BP, while the smaller (4 ft. long)



Sarsens in Clay-with-flints, Walter's Ash

From an old photograph by courtesy of Messrs. T. Bristow and Bros.

[*To face p.* 2

has typical HP pebbles, well-rounded and black-skinned, among the coarsely-rounded flints, suggesting that the typical HP was of earlier date and in its destruction contributed material to the BP type. Similar cases are seen at Amersham Town, and are reported from Kiln Common, but have not been fully studied.

The distribution of these three types is dissimilar. *Sarsens* are scattered over most of the area: there are barren patches (which may be due to observation-failure), the largest being a triangle with Hambleden (784.866), Great Missenden (894.014) and Hedgerley (969.874) as its apices. Sarsens are most numerous in an area about 2½ miles by one mile, running NE. from Naphill (841.977), near Bradenham, to Kiln Common (870.013), within which the stone has been extensively worked for kerbstones, setts and building-stone, at Walter's Ash (836.983) and Denner Hill (856.998). These blocks, up to 12 ft. long, and in one case (quarried for Windsor Castle) estimated to weigh fifty tons (Prestwich), were formerly found by probing the rich reddish loam (Clay-with-flints) which here covers the Chalk (Plate 1). Many sarsens are found in the same deposit at Lane End (815.922).

Hertfordshire Puddingstone extends in great quantity from its native county, at Flaunden (003.018) and Sarratt Church (039.984), some four or five miles westward, keeping north of the Chess (except about Chenies), as far as Chesham (956.015), where it is particularly abundant; but it then stops abruptly, except for a few odd blocks northwards at Lye Green (978.034) and Chesham Vale (963.041), a southward trail to beyond Amersham (944.963) and a westward trail through Great Missenden to Kiln Common (871.013) and Nanfan (867.009).

Bradenham Puddingstone is much less abundant than the other types, perhaps counting one-tenth of their (fairly equal) numbers. It seems almost confined to an area about twenty-four miles (SW.–NE.) by seven or eight, from Cookley Green (696.902) and Stonor (741.891), in South Oxfordshire, to Dagnall (992.163) where both kinds of puddingstone have quite lately been found. This area has an easterly bulge to include Little Missenden (921.990), with a south-easterly trail through Amersham to a solitary block that was formerly a mounting-stone outside the Pheasant Inn, Chalfont St. Giles (994.937). A smaller block also exists at High Wycombe (866.939). This area incorporates the area of maximum sarsens.

No puddingstones of either kind have been found north of the Chiltern scarp, except in the gaps at Princes Risborough, Wendover and Dagnall. Apparent exceptions at Aylesbury, Hartwell and Doddershall are probably due to human transport. Sarsens have been recorded along or near the course of the Icknield Way from Wendover to south of Ipsden, especially about Bledlow.

3. SIZE OF STONES

The twelve largest HP blocks recorded in the area are given in the table below:

NAT. GRID REF.	LOCALITY	DIMENSIONS
037.105	Water End, Great Gaddesden, opposite National Trust land	8′ 0″ x 5′ 6″ x 2′ 0″
956.015	Chesham parish church, SE. side of doorway	7′ 6″ x 5′ 3″ x 1′ 6″
960.016	Chesham, National Provincial Bank	7′ 3″ x 2′ 4″ x 1′ 6″
900.043	The Lee village green (from Mobwell gravel-pits)	7′ 3″ x 3′ 6″ x 1′ 4″ 6′ 6″ x 4′ 7″ x 1′ 5″
956.015	Chesham parish church, SW. side of doorway	6′ 0″ x 3′ 3″ x 1′ 6″
138.075	St. Albans, Kingsbury Mill	5′ 8″ x 4′ 6″ x 1′ 6″
146.316	Pirton parish church, NW. buttress	5′ 6″ x 2′ 7″ x 1′ 4″
900.043	The Lee (from Mobwell)	5′ 0″ x 3′ 6″ x 1′ 3″
956.015	Chesham parish church	
	S. aisle, mid-buttress	4′ 10″ x 4′ 2″ x 1′ 0″
	SW. nave-buttress	4′ 4″ x 4′ 0″ x 1′ 3″
974.003	Chesham, Weirhouse Mill	4′ 0″ x 3′ 0″ x 1′ 6″

The largest BP blocks are all at Bradenham, not in the well-known row from church to main road, but behind the church in Stony Meadow and The Coppice (830.974 to 833.973), where the largest is 12 ft. × 9 ft. with six others over 10 ft. long and thirty over 5 ft. The only rivals are on Cholesbury Common (933.072—6 ft. × 3 ft. 4 in. × 3 ft.), in Town Farm yard, Little Missenden (922.988—5 ft. × 4 ft. 8 in. × ?), and in the worked-out quarry alongside the Henley–Stonor road (734.880—5 ft. × 2 ft. 10 in. × 1 ft., a sarsen with pebbles along one edge), but there are several not much smaller at Wendover.

The largest *sarsens* are nearly all in a pit (895.057) at the far end of a ploughed field from which they were moved in 1911, about 300 yds. due N. of the Gate Inn and about halfway between the road and Lordling Wood, formerly in Wendover, but now in The Lee parish. According to Sherlock and Noble (1912), one is 15 ft. long, but the largest now visible among the dead brushwood covering them is about 8 ft. × 5 ft. × 4 ft. One measuring 6 ft. × 5 ft. × 4 ft. was removed in 1911 to The Lee village green (900.043) where it stands on a brick pedestal and bears an inscription.

From within the grounds of 'The Stone' Maternity Home, Chalfont St. Giles (992.936), can be seen a sarsen about 7 ft. long and 15 in. thick. It was originally a footbridge alongside a ford over the Misbourne, but the ford has been culverted and the sarsen incorporated in the roadway, so that its breadth could only be measured by crawling under it along the stream-bed.

There are a number of 6 ft. sarsens—at Westfield Farm, Bledlow (775.024), Bradenham (827.972) and Stonor House (741.890), but this last was originally at Turville, Buckinghamshire. Others of 5 ft. or more are at

Amersham Town (958.973), Lane End Common (815.922), Monks Risborough church foundations (812.045) and footbridge between there and Askett (812.048), Nash Lee, Ellesborough (843.084) and Winchmore Hill (933.950). Successively smaller ones are at Cadmore End, Great Missenden church, Bledlow church, Chalfont St. Giles church, Wendover and Ewelme school (this last 3 ft. 4 in. × 2 ft. 8 in. × 10 in.). The measurements given vary in accuracy: the varying shape of the stones and their frequently awkward positions make even the most careful taping somewhat uncertain. The third dimension, in particular, is often too small, giving the height above ground only.

4. POT-HOLING

A remarkable feature is the pot-holing seen in a few sarsens, and even in some conglomerates. The Rev. E. C. Spicer (1905) noticed one in a sarsen at Walter's Ash. In the case of the large sarsen already described at 'The Stone' Maternity Home, the visible joint-face shows several pot-holes in section.

At Winchmore Hill, on the Recreation Ground opposite the Village Hall (933.950), is a 5 ft. long sarsen, believed to have been dug up in widening Horsemoor Lane, 300 yds. away, about 1912: it is a tapering cylinder, about 2 ft. across in the middle, and with constrictions. It shows several unmistakable pot-holes. A very similar one was discovered at Webster and Cannon's brickfield at Aylesbury (822.143), on the occasion of an excursion of the XVIII International Geological Congress in 1948. It was not measured and has since been buried. Pot-holes may also be seen in the large blocks of sarsen and BP left in the abandoned gravel-pit that follows for a long distance alongside the Henley–Stonor road (733.879 and southwards).

A sarsen with a good pot-hole stands by the Black Lion Inn at Naphill (832.975), and a more doubtfully pot-holed sarsen is one of several by the Barley Mow Inn (911.012) between Great Missenden and Hyde Heath.

This pot-holing affords new evidence that the clay-with-flints is of glacial origin. The glaciation was purely local, however, as this region is quite devoid of the far-travelled erratics that abound in the area of glacial gravels surrounding it, and was therefore not touched by the main ice-sheet.

5. EFFECT OF HUMAN AGENCY ON DISTRIBUTION

In interpreting the distribution of these boulders, allowance must be made for transport by human agency. In some cases this is known to have taken place within this century, as with the well-known sarsen and HP so conspicuous on the village green at The Lee. The sarsen, as already stated, came from a field near Lee Gate, and the HP are probably from Mobwell.

Blocks of BP and sarsen were taken a century ago from Hampden (where hardly any can now be found) to Hartwell Park (Morris, 1867). When the Embassy Cinema was built in Chesham, a rockery on the site was bodily removed to Queensbury, Middlesex: according to a neighbour it included a 6 ft. long HP.

In July 1951 a long silage-trench was dug near Geary's Plantation, Flaunden (007.995), and yielded large numbers of slabs of HP: many of these were carted away for rockeries, including many to Chorleywood, outside the normal distribution area. Many small HP blocks have also been removed from the area between Cowcroft Wood (986.017) and White-end Park (983.006), where only small pieces now remain.

A number of BP blocks lie in Wallaby Wood, Whipsnade Zoo: according to the Superintendent they are 'the balance of a quantity purchased many years ago for use in connection with rockeries, etc.': he adds his regret that he cannot tell us the original source of the material. We strongly suspect Walter's Ash, but enquiry there has failed to confirm this, the possible records having been put into salvage during the war.

Modern landscape-gardening is not the only possible source of confusion. Some stones have been set up as parish boundary-marks, though they are not likely to have been moved very far. In pre-historic times, possibly in the Neolithic or Early Bronze Age, huge blocks of sarsen and HP (up to 7 ft. 6 in. long) were collected from the Chesham neighbourhood (where many others almost or quite as large are still to be seen), probably to form a stone circle, which in early Christian times served as foundation-stones for the buttresses of Chesham parish church. The name Ceasteleshamm, first recorded in the tenth century, but probably dating from the seventh, appears to mean 'The hamm [enclosure] by the heap of stones'—the other meaning of *ceastel*, a small fort, being inapplicable here.

Though no equally striking example of such incorporation of pagan monuments in the structure of Christian churches (as advised by St. Gregory to Archbishop Mellitus in A.D. 601, according to Bede's *Ecclesiastical History*, Bk. 1, Ch. xxx) is known in south Bucks, there are many such cases in other counties (see Johnson, 1912). Many other Chiltern churches have collections of large stones (S, with or without BP, most commonly) round or near the churchyard and/or in the foundations of the tower. Such are Amersham, Bledlow, Bradenham, Chalfont St. Giles, Chenies, Denham, Fingest, Hambleden, Great Hampden (S only), Great Missenden (S only), Little Missenden, Monks Risborough (S only), Nettleden and Sarratt (Hertfordshire, HP only). No similar accumulations (other than modern rockeries) are known at a distance from churches in the Chilterns, except in a number of blind alleys (yards, closes) in the old part of Chesham town.

The exceptional size of the Chesham church-tower stones need not imply, as sometimes suggested, special religious importance of the site: no other site had such a supply of large stones at hand.

Among place-names which refer to sarsens are Honor End (from 'Hanora', in which *han*=hone, whetstone), Whetstone (Middlesex) and probably Stony Green and Ibstone.

Although this survey is admittedly not complete, it seems worth publishing, if only to draw the attention of local geologists and archaeologists to gaps which it may be possible to fill.

A card-catalogue of all observed sarsens and conglomerates (with grid-reference, position, measurements and other notes) for south Buckinghamshire and adjacent parts of Oxfordshire and Hertfordshire, is deposited in the Buckinghamshire County Museum, Church Street, Aylesbury.

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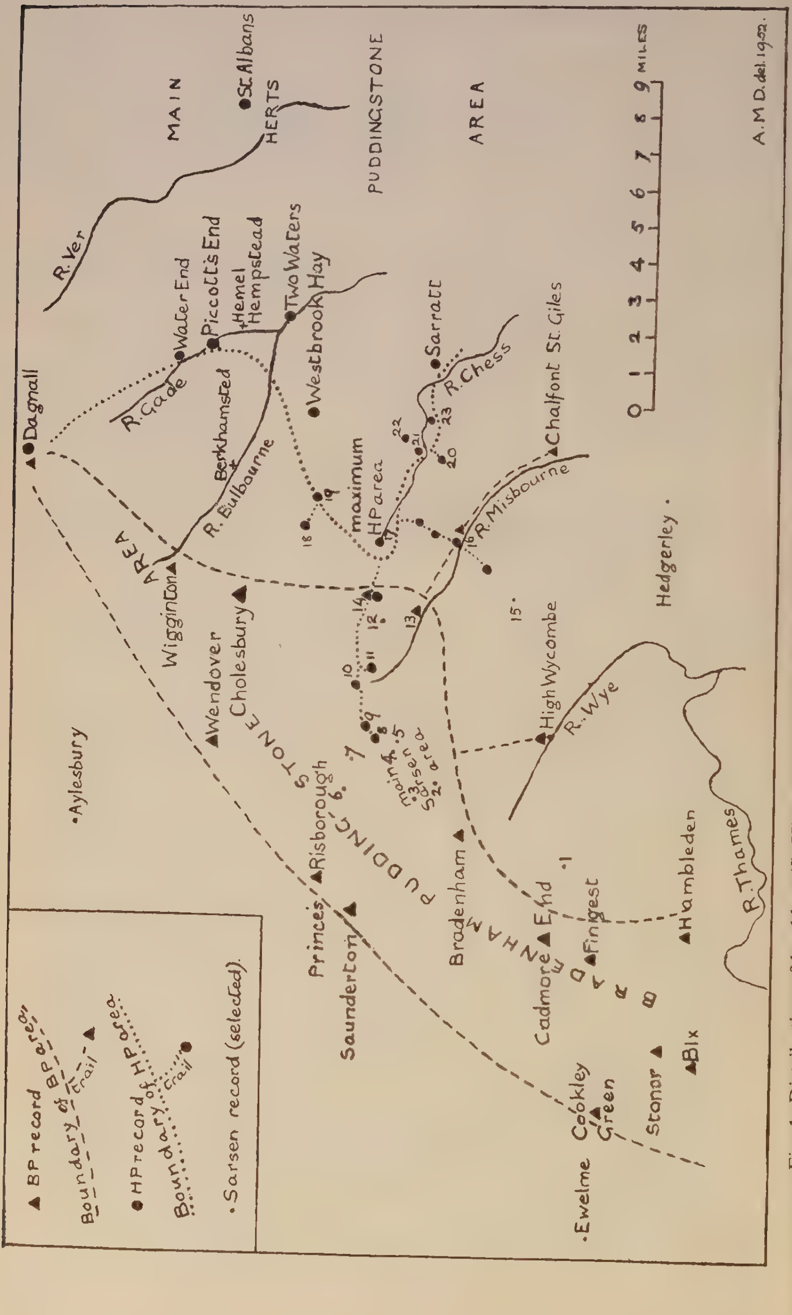


Fig. 1. Distribution of boulders (S, HP and BP) in the Chilterns (South Bucks and adjacent parts of Oxon and Herts)

7. EXPLANATION OF MAP

The map illustrating this paper is intended to be purely factual and not to suggest any explanation of the distribution of the puddingstones. To have plotted on it the occurrence of sarsens would have been a useless waste of labour, as they are almost everywhere, except in the Bulbourn Valley and the triangle mentioned on p. 3. The unnumbered HP half-way between 15 and 16 marks a cutting on the Amersham–Wycombe main road.

Key to reference-numbers on the map:

1. Lane End
2. Naphill
3. Walter's Ash
4. Denner Hill
5. Stony Green
6. Great Hampden
7. Honor End
8. Nanfan
9. Kiln Common
10. Mobwell
11. Great Missenden
12. Hyde Heath
13. Little Missenden
14. Hundridge
15. Winchmore Hill
16. Amersham
17. Chesham
18. Chesham Vale
19. Lye Green
20. Little Chalfont
21. Latimer
22. Flaunden
23. Chenies

POSTSCRIPT.—Since handing this paper to the Association we have received an offprint of a paper by Dr. E. A. and Mrs. E. L. Rudge on 'The Conglomerate Track' (*Essex Naturalist*, **29** (1), 17–31). The authors claim to have traced a prehistoric track from East Anglia to Thatcham, Berks, by means of an alignment of puddingstone blocks. Reserving any opinion on this general claim, we are only concerned with the part of the line that crosses our area. This corresponds in part with our 'Nanfan trail', continued both ways within the limits of the areas of the two types of puddingstone. The authors have recorded a number of sites that had escaped our notice, but none of these necessitates any alteration in our map. The paper contains two good photographs of the puddingstone foundations of Chesham parish church.

ACCOUNT OF A MUDFLOW ON BREDON HILL, WORCESTERSHIRE, APRIL 1951

By A. T. Grove, M.A.

[*Received* 25 *January* 1952]

BREDON Hill is perhaps the most remarkable outlier of the Cotswolds. On its north-west side it rises steeply from the flood-plain and terraces of the Avon, near Eckington, to a height of about 960 ft. at Bredon Tower. The general succession near Woolashill is as follows:

Inferior Oolite	100 ft. +
Upper Lias	270 ft.
Middle Lias	Marlstone 30 to 40 ft. Sand Beds 160 ft.
Lower Lias	200 ft.

The Marlstone is more resistant than the beds above and below it, and on the west, north and east sides of Bredon it forms ledges and flat-topped spurs at heights of between 400 and 600 ft. The hill is capped by Inferior Oolite. The Oolite forms a mural cliff around the crest of the hill except on the south side, where it dips conformably with the general slope of the hillside and extends down to the 300-ft. contour. There, according to the Geological Survey map (Sheet 44, Old Series), it is let down by a fault against the Lower Lias.

Near Woolashill, where the mudflow occurred, the hill-profile is made up of four clearly-marked sections. At the crest there is the steep outcrop of the Inferior Oolite with a short scree-slope at its base. The scree rests on the hummocky surface of the Upper Lias. This formation, consisting almost entirely of shaley clays, is here encumbered with tumbled blocks of Oolite. The mean angle of slope is about 8°, but the entire outcrop has been affected by slipping, with the formation of long hollows running along the contour. In March 1951, these hollows were occupied by standing water. Below the Upper Lias, the third section of the hill-profile is formed by the Marlstone and Sand Beds. These give slopes of about 18° below the narrow Marlstone ledge, and are fairly well wooded. At the 400-ft. contour, the profile again assumes a gentler gradient of 6° or 8° at the outcrop of argillaceous beds in the Lower Lias (Fig. 1). In the same month a landslide was reported in the local press as having overwhelmed three cows at Woolashill Farm. The site was visited on the following day and again on later occasions. The writer was fortunate enough to see the so-called landslide in motion on 10 April.

Numerous springs are thrown out at the base of the Inferior Oolite where rainwater, which has percolated through the fractured, pervious

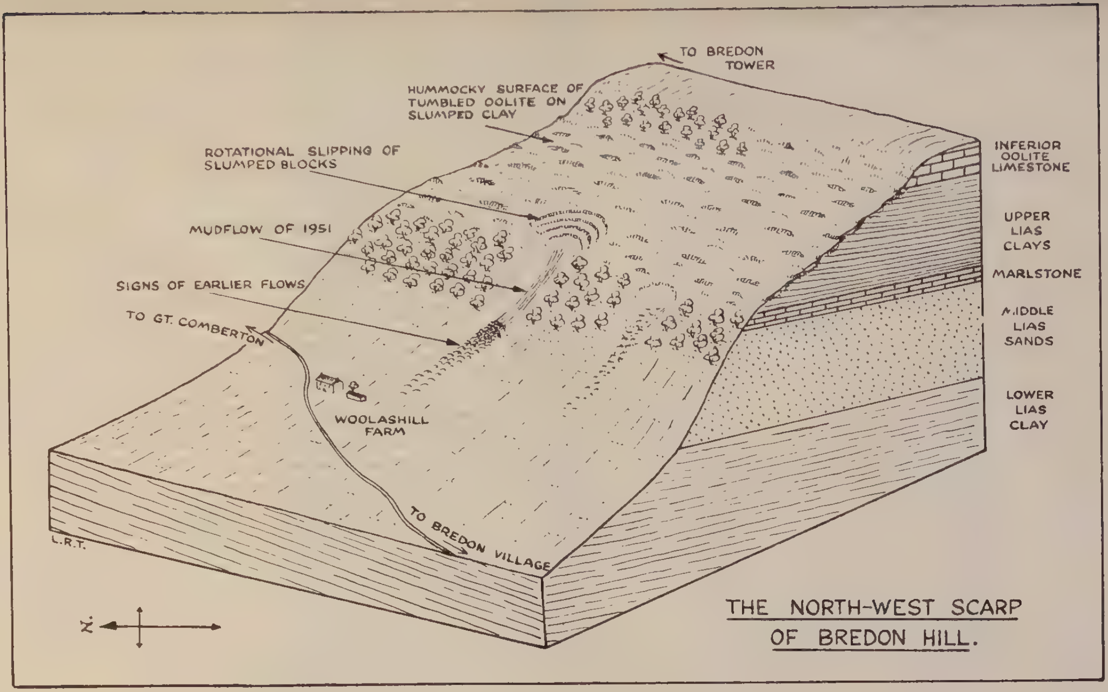


Fig. 1. Block diagram to show relation of mass-movements to structure

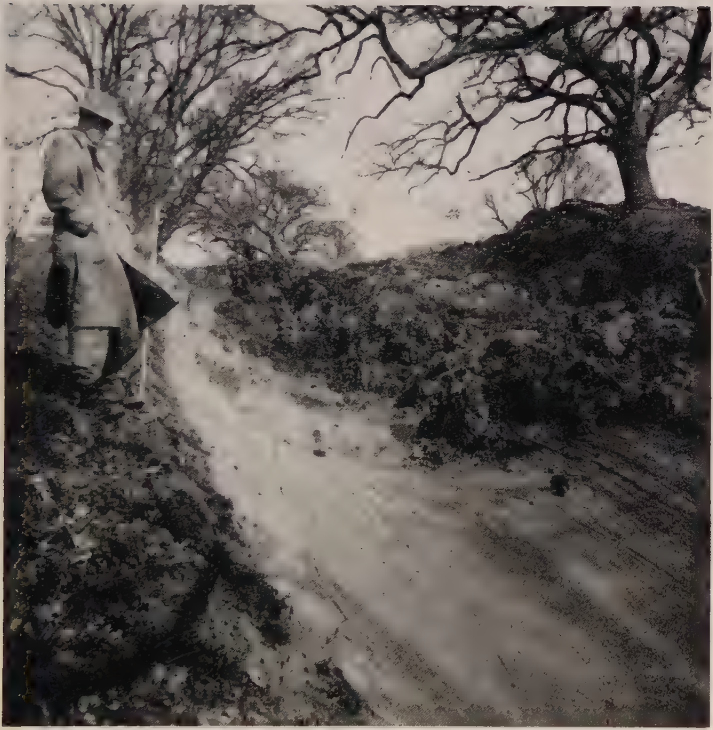
beds, is held up by the Upper Lias clays. At lower levels, a few small springs emerging from the Sand Beds of the Middle Lias rise in small valley-heads which notch the Marlstone ledge. The recent landslides mainly involved Upper Lias clays which were ejected through one of these notches and flowed for a distance of some 150 to 200 yds. on to the gentler slopes of the Lower Lias some 150 ft. lower down.

The landslides are complex earth-movements and bear some resemblance to valley-glaciers in motion. At the head of the valley, in a slope-depression above the Marlstone, blocks of Upper Lias clay were in motion at the end of March and during April. Scarplets, 3 to 12 ft. in height, showed fresh exposures of clay in many places, and at the lateral margins of the moving blocks, the turf had been cut through cleanly as though by a great knife. Entire blocks had shifted as units with little apparent surface distortion.

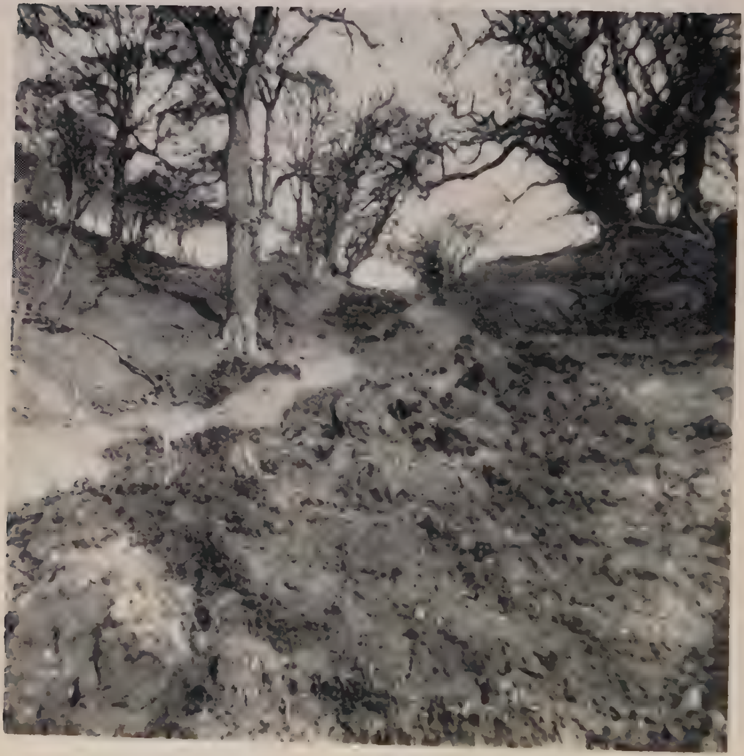
Below the zone of slumping, within the Marlstone notch, heterogeneous masses of clay, turf and Oolite were squeezed out from time to time, and slid down a smooth-sided chute formed by earlier movements. On 10 April the writer saw one of these masses of earth in motion. It originated at the toe of the lowest slumped block and slid as a unit about 70 ft. long, 15 ft. wide, and little more than 5 ft. thick, down the chute, lubricated by a small trickle of water. The gradient was about 25° and the rate of movement 50 ft. in half an hour (see Plates 2 and 3). At slight humps in the chute, pressure waves a few inches high formed across the moving mass. Cracks appeared in the forward part of the front wave, the foremost section broke off and moved on, sliding down the slope. This process was repeated a few times until the whole mass had re-formed into a unit below the hump. On the gentler gradient lower down the hill, the rate of movement decreased and lumps of turf and sticks were thrust up from the tongue of what had become a slow earthflow. The surface of the mud crumpled and fissured in all directions and the mass became more or less stationary.

The slides of 1951 covered distances of about 200 yds. The outlines of older flows, long covered with turf, can be distinguished. One extends about 150 yds. beyond the latest flows and is said to have been active about 1930. Other flows have evidently occurred in adjacent valleys from time to time. In a small valley immediately to the north, the earth still seems to be in motion; a water-pipe has been bowed above the surface, and numerous small water-logged depressions have formed. To the south, the outlines of four much older and somewhat larger flows have been mapped.

The recent landslides can be attributed to the unusually high rainfall during the winter of 1950–1. Records from Tewkesbury show that the rainfall during the first three months of 1951 was nearly 3½ ins. above



Mudflow on Bredon Hill, April 1951. Mass of clay, turf and Oolite beginning to slide down a smooth-sided chute



Mudflow on Bredon Hill, April 1951. Crumpled surface of earthflow average, and this was at a season when transpiration and evaporation are at a minimum and the water-table in the Oolite is reaching its peak-level.

The landslide which was observed has been described in some detail because eye-witness records of such movements in this country, at a distance from the coast, are not frequently encountered (Murchison, 1844, p. 59; Ward, 1945, p. 196). These movements on Bredon are on a small scale, but preliminary study suggests that they may be associated with cambering of the Inferior Oolite, that is, with movements which have caused deformation on a much larger scale.

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THE DEVELOPMENT OF THE LYN DRAINAGE SYSTEM AND ITS RELATION TO THE ORIGIN OF THE COAST BETWEEN COMBE MARTIN AND PORLOCK

By Scott Simpson, M.A., Dr. rer. nat., F.G.S.

[*Received* 27 *November* 1952]

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ABSTRACT.—A study of remnants of an abandoned valley of the River Lyn and of the remarkable rejuvenation of the river-system leads to the recognition of four stages of capture of the river by coastal erosion. The implications for the origin of the coast, of the exceptional rate of its retreat thus demonstrated, are considered, and it is suggested that the coast is very young and has been developed as a marine fault-line escarpment.

1. THE CATCHMENT AREA

In a recent study of erosion-surfaces on Exmoor, Balchin (1952) has shown that all the higher summits of Exmoor fall within a well-defined region which is surrounded by a marked erosion-surface, standing generally above 1000 ft., and rising nowhere above about 1250 ft., which he names the Lynton surface. The line that separates these two regions in North Exmoor is shown in Fig. 1.[1] In this area it appears in the field as a steep slope, generally fully 200 ft. high. This striking feature is in no way structurally determined, and there seems no doubt that it represents an ancient cliffed coast. Only the East Lyn breaches this cliff-line on the west side of Exmoor, for in general the line coincides with the watershed between the drainage of the Lynton surface and that of the inner region which ultimately collects in the River Exe.

The peculiar morphology of the North Devon and Somerset coastal area between Combe Martin and Porlock is determined by the way in which the coast-line truncates the Lynton and inner Exmoor surfaces. Unlike South Wales across the Bristol Channel there are no lower coastal platforms, and thus the cliffs (with their hog's-back slope) fall 1000 ft. to the sea. The rivers, descending the 1000 ft. within a distance of four to eight miles, have their lower courses deeply incised below the Lynton surface, which is extensively preserved on the broad interfluves.

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[1] The writer differs from Balchin in that he believes this line to reach the coast about three miles east of the Foreland. Thus the line shown does not exactly agree with that drawn by Balchin.

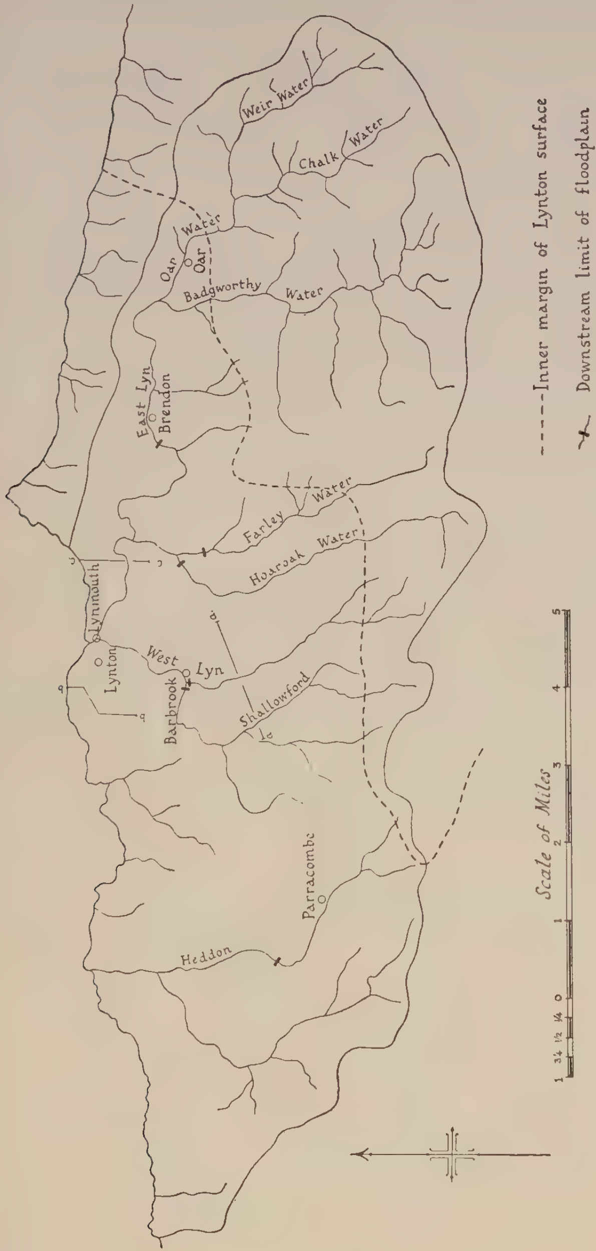

Fig. 1. The catchment area of the Rivers Lyn and Heddon

The Lynton surface, as might be expected if it is to be interpreted as a marine platform, slopes outwards from inner Exmoor, and the north-north-westerly trend of the upper courses of the streams draining it agrees with this slope. The trend is clearly seen in the headwaters of the Heddon, the Shallowford stream, the West Lyn and the Hoaroak and Farley Waters. A remarkable feature, for which no explanation has yet been found, is the way in which the lower courses of these streams trend round into a north-easterly direction. This is seen in the west branch of the Heddon, the Shallowford stream and the Hoaroak Water.

The East Lyn, formed by the confluence of the Badgworthy, Chalk and Weir Waters, which drain the northern sector of inner Exmoor, flows west-north-west, receiving first the conjoint Hoaroak Water and Farley Water and then the West Lyn on its left side. The Heddon would form a third such left-bank tributary if the course of the East Lyn were extended without change of direction into the area now covered by the sea.

Whereas the north-north-westerly trending streams may be interpreted as superimposed from a sedimentary cover, which once overlay the Lynton surface and are adjusted to the geological structure in detail only, the East Lyn is a strike-stream working along a band of slates between thick sandstones.

2. VALLEY-FORMS

There is a striking contrast between the valleys of the lower and middle reaches of the rivers within the area of the Lynton surface. The difference arises from a recent strong rejuvenation which has extended only a limited distance upstream. Thus the lower reaches have valleys which are typically juvenile while the middle reaches are more mature.

The valley-form of the lower reaches is a V-shaped gorge, so narrow at the bottom that there is no room for a road beside the river. The valley-sides are too steep for cultivation and are clothed with oak-woods, with here and there a cliff of naked rock. There is no room in these valleys for a village and no call for one because the arable land lies several hundred feet above their floors. The single exception is Lynmouth which originated as a fishing village and developed as a resort. But even here, at the river mouth, there has only been room to build on the river-bed itself, as has been proved by the flood which washed away so many houses merely by claiming for itself again the boulder beds on which they had been built.[1]

The middle reaches, on the other hand, are relatively broad and open, and there is always a flood-plain. The valley-sides are not so steep and are devoid of rock outcrops though still often wooded. The villages of Parracombe, Barbrook, Brendon and Oar lie within these middle-reach valleys.

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[1] In the references at the end of this paper will be found details of publications dealing with the meteorological and other phenomena of the catastrophic flood of August 1952.

The valley-sides in the middle reaches are markedly convex, and it is clear from the transverse profiles that there is always a valley within the valley. Thus the middle reaches show evidence of a rejuvenation earlier and more extensive than that which has brought into being the gorges of the lower reaches. This is illustrated in Fig. 2 *a*. It is found that the steep-sided inner valley-slope has an average gradient of 1 in 3.

The average gradient of the valley-sides in the lower reaches is 1 in 1½, and this appears to be the characteristic hanging slope developed in this area when a hillside is undercut; thus it is also the average slope of the hog's-back above the marine cliffs. The sections *b* and *c* of Fig. 2 illustrate the cross-profiles of these lower reaches and show the sea-cliff profile as well.

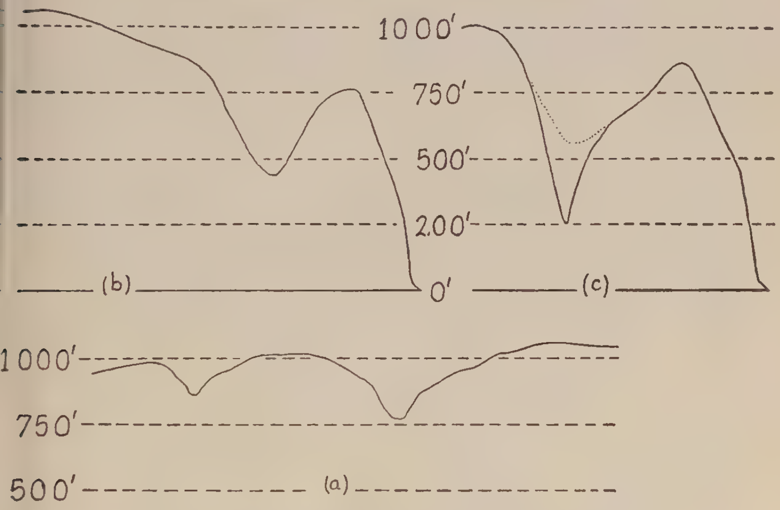


Fig. 2. Transverse profiles along the lines shown in Fig. 1
(a) Shallowford stream and West Lyn Valleys
(b) Valley of Rocks
(c) East Lyn Valley

3. THE LONG PROFILES

The long profiles of the rivers (Fig. 3) have been plotted from the contours shown on Ordnance Survey 2½-inch maps. Each river-profile shows a concave upper part and a convex lower part, so that the lowest gradients appear in the middle reaches. It is here, of course, that the valleys have their most mature appearance and possess a narrow flood-plain. However, even in the middle reaches the profiles can scarcely be called graded, for they all show a number of prominent steps.

A striking feature is the way in which the West Lyn and Hoaroak–Farley Water tributaries hang above the East Lyn. Two factors probably account for this phenomenon: first, the more rapid recession in the main stream of the steep gradients resulting from rejuvenation, the rate of erosion being supposed to increase exponentially with the volume; and, secondly, the lesser resistance to erosion presented by the slates which outcrop along the course of the main stream.

It may be noted that the Heddon differs from the Lyn in that there is some flattening out of the gradient at its mouth, so that there is a second inflexion in the profile and the beginning of a concave lowest reach. An explanation is that, while rejuvenation of the Heddon has ceased, it is still affecting the Lyn.

4. THE VALLEY OF ROCKS

The Valley of Rocks is a remarkable dry valley obviously eroded by a stream of water which once flowed westwards from its wind-gap commencement, over 400 ft. above Lynmouth, to Wringcliff Bay, where it hangs 200 ft. above the sea. It takes its name from the rocky 'striding-edge' on its right side which has clearly come into being through the meeting of the seaward migrating valley-side and the landward retreating hog's-back slope above the sea-cliff; a mode of origin closely paralleling that of an alpine *arrête*.

There are only two ways in which such a dry valley may be conceived to have originated. These are either by capture of the headwaters of the stream which originally traversed it, or by a temporary diversion of drainage such as might have occurred if ice filling the Bristol Channel had diverted the drainage along the coast. The latter explanation is highly improbable in view of the absence of any other evidence that such an ice-sheet ever existed. Actually there is no need to consider this hypothesis because the former explanation can be substantiated without difficulty.

The Valley of Rocks (Fig. 4) exactly continues the line of the lower East Lyn Valley, and it is obvious that the retreat of the coast to form Lynmouth Bay may have resulted in the capture of the headwaters of an East Lyn which once extended westwards through the Valley of Rocks. This would imply a rejuvenation upstream from the capture, and it will be shown in Section 6 (p. 20) that the amount of rejuvenation that has taken place is consistent with the height that the dry valley hangs above the river-mouth. Strong additional confirmation of the hypothesis is provided by a comparison of the transverse profiles (see Fig. 2 *b* and *c*) of the Valley of Rocks and the lower East Lyn Valley. It may also be remarked that another rocky 'striding-edge', like that of the Valley of Rocks, occurs in an exactly analagous position between the East Lyn and the sea immediately east of its mouth.

5. VALLEY REMNANTS WEST OF THE VALLEY OF ROCKS

Just as the Valley of Rocks forms a wind-gap above Lynmouth, there is a second wind-gap, leading to a shorter and steeper dry valley, 150 ft. above the floor of the Valley of Rocks at its termination above Wringcliff Bay. This is the dry valley in which Lee Abbey lies. It exactly continues the westward trend of the Valley of Rocks and the upper south valley-slope is continuous from the one into the other (Fig. 4). Thus a second capture is suggested (at Wringcliff Bay) which must, however, have preceded the Lynmouth one in time.

There are two further valley remnants which may be attributed to the extended Lyn Valley. West of Lee Bay, Woody Bay is backed by a high sea-cliff with the usual hog's-back slope above it. At two points, however, the sea-cliff parts company with the hog's-back slope. The first of these is Crock Point, which is the headland between Lee Bay and Woody Bay. Here the steep slope flattens out at 200 ft. above the sea while the cliff swings out round the point which thus is low and flat-topped. Clearly the slope behind Crock Point is not homologous with the hog's-back but with the valley-side. The low level of the old valley-floor at Crock Point shows hat it was formed after rejuvenation. It may well be a continuation of the Lee Abbey dry valley beyond the bite taken out by the sea in Lee Bay.

The other valley remnant is at Martinhoe Manor, immediately west of he mouth of the Woody Bay stream (Fig. 4). Here again the steep slope lattens out before the cliff is reached, but in this case at about 275 ft. above he sea.

6. RECONSTRUCTED PROFILE

If it is assumed that the rejuvenation, which has resulted in the destruction of the valley flood-plains and has produced the convex long-profile on he lower reaches, is the result of the sudden capture of the Lyn at Lynnouth, it should be possible by extrapolation to discover the height of he pre-capture valley-floor at Lynmouth.

The usual procedure in making such an extrapolation is first to obtain an equation to describe the form of the long profile in the reaches where it s preserved. The data required are obtained by instrumental levelling. It s, however, very doubtful whether the work involved in this procedure vould be justified in the case of the Lyn, for the graded reaches are too hort to yield useful equations. But as the distances to be extrapolated are ery short and great accuracy is not required, a more rough-and-ready nethod may be applied.

From the gradients taken from the contours it is found that the preserved lood-plain remnants in the middle reaches have a stepped profile and here is in general more than one minimum gradient. For the purposes of calculation the nearest minimum gradient to the downstream end of the flood-plain has been selected for each stream. On the assumption that the valleys were graded downstream from the reaches yielding these gradients, it is possible to extrapolate for each tributary stream to obtain the pre-capture height of the East Lyn at each tributary confluence. In extrapolating a constant gradient has been assumed between the flood-plain remnant and the confluence with the main stream. Thus it might seem that the values obtained would be minima since, in a graded profile, the gradients fall off downstream. However, the assumption that the streams were graded is only approximately true, and the actual mean gradients would have been greater than the minimum values used in the calculations. Thus the two sources of error work in opposite directions and it is not known which is the more important.

The following table shows the data used in reconstructing the pre-capture long profile of the East Lyn:

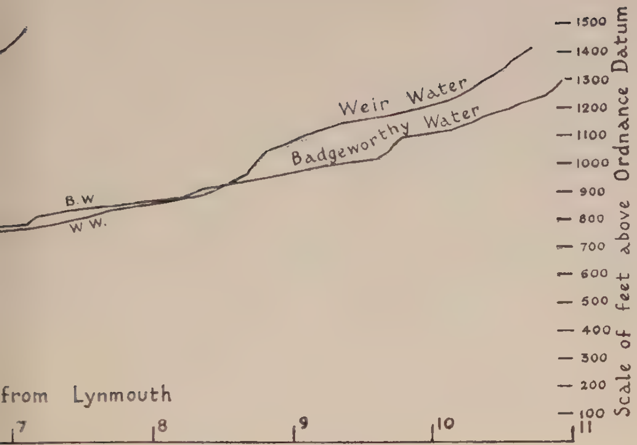
Stream	Gradient of Flood-plain (ft. per mi.)	Height of Flood-plain (ft.)	Distance to Confluence (mi.)	Calculated Height of East Lyn (ft.)
Shallowford stream	88	675	1.81	516 at Lynmouth
Upper West Lyn	93	650	1.53	507 at Lynmouth
Farley Water	88	675	0.88	597 at Watersmeet
East Lyn	33	675	3.88	572 at Watersmeet
Heddon	69	550	2.61	376 at Heddon's Mouth

Height of valley-floor remnant at Myrtleberry spur	550 ft.
Highest point on floor of Valley of Rocks	475 ft.

Good agreement is obtained between the values from the two branches of the West Lyn. The value yielded by the Shallowford stream is preferred because the joint stream, if graded, would have a gradient no greater than the lesser one of the larger confluent.

No satisfactory value could be obtained from the Hoaroak Water, for it would appear that the requisite flood-plain remnant has not been preserved; the rejuvenation-head resulting from the capture has overtaken that of an earlier phase of rejuvenation. The value yielded by the Farley Water for the height at Watersmeet is considerably higher than that yielded by the East Lyn. The East Lyn value is preferred since it is supported by the height of the preserved valley-floor on the Myrtleberry spur immediately below Watersmeet, and because the flood-plain in the Farley Water is poorly developed and the gradient employed is probably inadequate in consequence.

Thus using the heights 376 ft. at Heddon's Mouth, 516 ft. at Lynmouth, 572 ft. at Watersmeet, the following gradients are obtained for the reconstructed East Lyn long profile:



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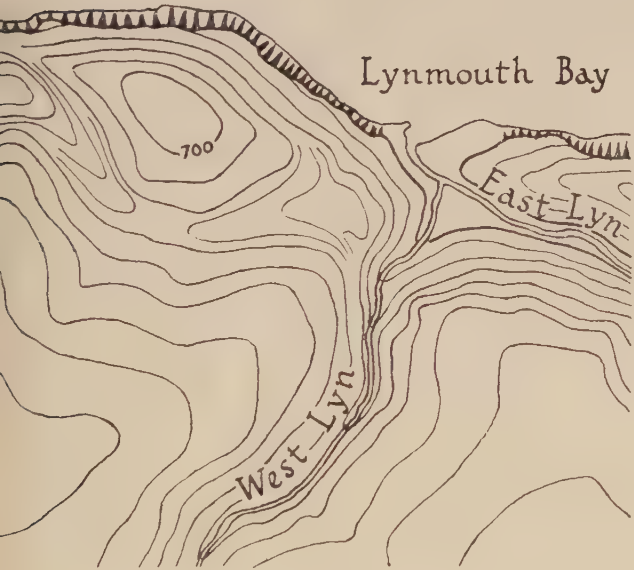

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Brendon to Watersmeet	33 ft. per mi.
Watersmeet to Lynmouth	31 ft. per mi.
Lynmouth to Heddon's Mouth	29 ft. per mi.

In Fig. 3 is shown the profile obtained by connecting the heights calculated. It is seen that the original East Lyn Valley was dismembered in a series of stages by marine capture at (a) Heddon's Mouth, (b) Woody Bay, (c) Wringcliff Bay, (d) Lynmouth. The capture at (or beyond) Heddon's Mouth was early, for the steep gradients produced have had some time to migrate upstream, leaving lower gradients at the mouth today. The Woody Bay capture produced the steep valley (now dry) at Lee Abbey. Before this had retreated far, a new capture at Wringcliff Bay diverted the river and 'froze' the rejuvenated slope at Lee Abbey. The steep gradients produced by this capture are similarly preserved in the Valley of Rocks today as a result of the last capture at Lynmouth. The Lynmouth capture is so recent that the West Lyn still preserves the phenomenal fall of 400 ft. in its last mile—the fall which caused much of the catastrophic destruction at Lynmouth in the flood of 15 August 1952.

7. DENUDATION HISTORY AND ORIGIN OF COAST

The most fascinating implication of the dismemberment of the Lyn Valley by the sea concerns not the history of the Lyn but that of the coastline and the origin of the Bristol Channel. It is a well-known fact that, along the entire coast of Wales and also that of Devon and Cornwall west and south of Combe Martin, there are coastal platforms at various heights which constantly intervene between the coast and any high ground inland. Only between Combe Martin and Porlock does land above 1000 ft. reach to the very coast. The question naturally arises as to why this should be.

The rapid coastal retreat, proved by the dismemberment of the Lyn drainage-system, suggests that erosion might have removed any such platforms if it ever existed. But the paradox presented by the fact that such rapid coastal retreat has taken place only here, where the rocks are most resistent, the cliffs are highest and the wave-attack oblique, remains to be resolved. The only possible explanation of the intense marine erosion is surely that the coast is a new one which has not yet reached equilibrium.

A new coast can be created in one of four ways:

(a) by rise of sea-level
(b) by faulting
(c) by warping
(d) by the rapid erosional exploitation by the sea of a zone of weak rocks.

Since the Pliocene and Pleistocene history of the morphology of the whole of western Great Britain requires a persistently falling sea-level, the first explanation (a) does not arise. Further, as the sea-level had already fallen to below 400 ft. before the dismemberment of the Lyn Valley commenced, the explanations by faulting (b) or warping (c) require a late Pliocene or Pleistocene age for a tectonic feature involving a displacement of the order of 500 ft. at least. This seems improbable in the extreme. Thus only the explanation (d), in terms of the rapid local advance of the sea along a special weak belt, arises. This naturally suggests a fault bringing soft Mesozoic rocks close against Devonian sandstones. At Watchet, nearby to the east, and along the Glamorgan coast across the Bristol Channel, the Lias extends to below sea-level. Deep fault-bounded Trias basins occur in the Armorican mountains generally, and they are typically present at Porlock where the high coast ends. It is not unreasonable to suggest that such a basin as that of Porlock Vale once extended westwards past the Foreland. There may well have been a time when the coast east of Combe Martin swung many miles to the north and may even have joined the South Wales coast on the east side of Swansea Bay. If then the coast, retreating eastwards, encountered Lias clays within the Trias basin postulated, it might have quickly extended towards Bridgwater and brought virtually the present coast-line into existence as a marine fault-line escarpment.

It is now possible to attempt a summary account of the history of the Lyn drainage-system. Balchin ascribes a Tertiary age to the Lynton surface, but this seems open to question and an alternative view is that the surface was of Mesozoic origin and was once blanketed in Mesozoic sediments. However this may be, it seems probable that the broad lines of the Lyn drainage were superimposed on the Lynton surface in Tertiary times. The relatively shallow valleys, of which traces are left on the present upper valley-side slopes in the middle reaches of the Lyn rivers, date back to an early stage of which we have little knowledge. Then followed a period of falling sea-level, which resulted in the stepped profiles of the middle and upper reaches of the rivers. The sea had fallen to below 400 ft. above its present level while the Heddon was still a tributary of the Lyn. Possibly the lowest preserved flood-plains in the middle reaches were graded to the sea which cut the Georgham Surface of Balchin. How much farther the sea may have fallen before the decisive break-through, which initiated the present coast-line, it is not possible to estimate from evidence in the area under consideration, though information should be available in the morphology of the streams of East Somerset and Glamorgan. The earliest date for the new coast-line is that for which the sea-level first dropped appreciably below 400 ft.

With the initiation of the new coast-line, its rapid retreat also commenced, and the successive captures took place from Heddon's Mouth to Lynmouth. The height of the valley-floor remnant on Crock Point indicates that, at the time of the capture in Woody Bay, the sea-level cannot have stood appreciably above 100 ft. This would presumably have been quite late in the Pleistocene. It may be noted that none of the Pleistocene raised-beaches known from the South Wales coast have been detected between Combe Martin and Porlock, so that it would seem that coastal retreat has persisted until very recent times. In fact there is plenty of evidence that the retreat has by no means ended yet, and it may be supposed that the gain of the sea at the expense of the River Lyn will continue.

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FIELD MEETING AT THE STOUR ESTUARY

Sunday, 18 May 1952

Report by the Directors: A. G. Davis, F.G.S., G. F. Elliott, F.G.S. and H. E. P. Spencer, F.G.S.

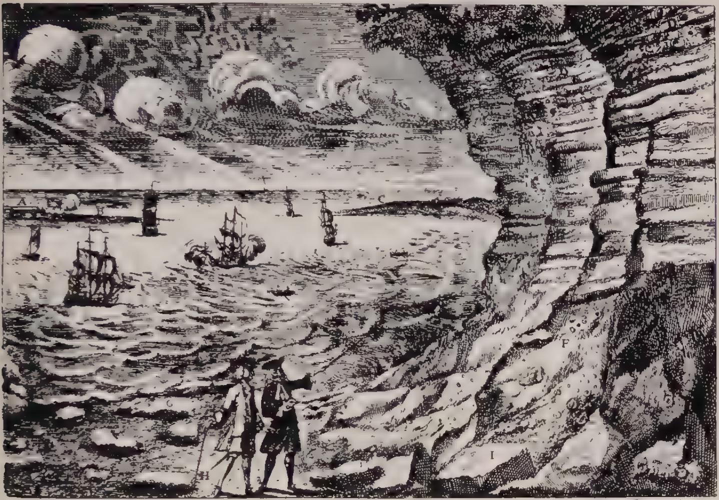
[*Received* 22 *August* 1952]

THIRTY-ONE members and friends assembled at Charing Cross and proceeded to north Essex, where they were joined by six more. After lunch at Ramsey the party visited the Harwich foreshore, where one of the directors (G.F.E.) gave a brief account of the local succession in the London Clay and its correlation with that of countries across the North Sea and with the rest of England. Some copies of an old engraving (1730) of the section at this spot were handed round so that members might see the considerable changes brought about there in the last two centuries (see Plate 4). Returning to the coach, the party proceeded round the head of the estuary at Manningtree and into Suffolk. They examined the section of Pleistocene brickearth on the shore at Stutton Ness. The directors (A.G.D., H.E.P.S.) spoke respectively on the rich molluscan fauna of the brickearth and on the history of its study, and on the local succession and extent of the deposit (see notes on pp. 25–30). After successful collecting there, the party were taken through a surprisingly hilly part of Suffolk to Harkstead. Here a hurried descent through fields and marsh brought them to a fine cliff-section of contorted and gravelly drift resting on and impacted into London Clay; one of the directors (H.E.P.S.) spoke on the relation of this marginal deposit to the brickearth earlier seen, and on the extent and possible mode of formation of the whole deposit. Tea was taken in Stutton; Mr. Davis exhibited some old literature and portraits of geological worthies connected with the district. The President proposed a vote of thanks to the Directors and to the Secretary, Miss J. M. Spires, after which the main party returned to London.

EXPLANATION OF PLATE 4

Fig. 1. Harwich cliff in the early eighteenth century: London Clay (E) with stone band (I) near the base of the cliff, capped by Red Crag (D). After Samuel Dale, *The History and Antiquities of Harwich and Dovercourt*, etc., pl. 8, London, 1730.

Fig. 2. Approximately the same spot as in Fig. 1, May 1952. Marine erosion has cut back the cliff with complete loss of the Red Crag: the stone band outcrops along the foreshore, the London Clay below and above being obscured by beach material and by the sea-wall and vegetation.



A. Land guard Fort B. The Andrews or Bars of Sand running from the Fort. C. The South or Dover Court Point of the Havens mouth. D.D The Strata of Sand, Gravel, Foſsil-Shells, and their Fragments. E. The Stratum of Blewiſh Clay divers Feet deep. F. The heap of Gravel, Sand, & Shells, &c. which caveing down from the Top ly at the bottom of the Cliff. G. Cliff-Stones which ly upon the Shore before the Cliff. H. Perſons Obſerving The Cliff. I. A Stone of the Lower or Stoney Stratum.

Fig. 1. Harwich Cliff in 1730

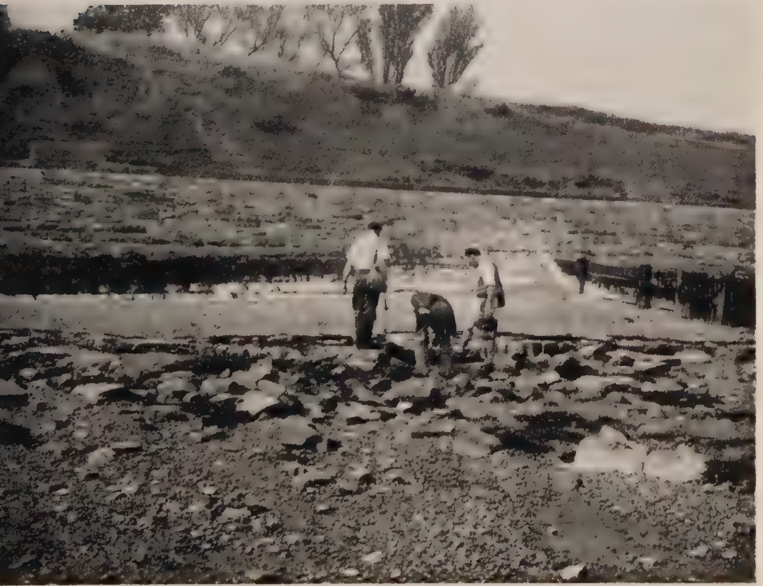
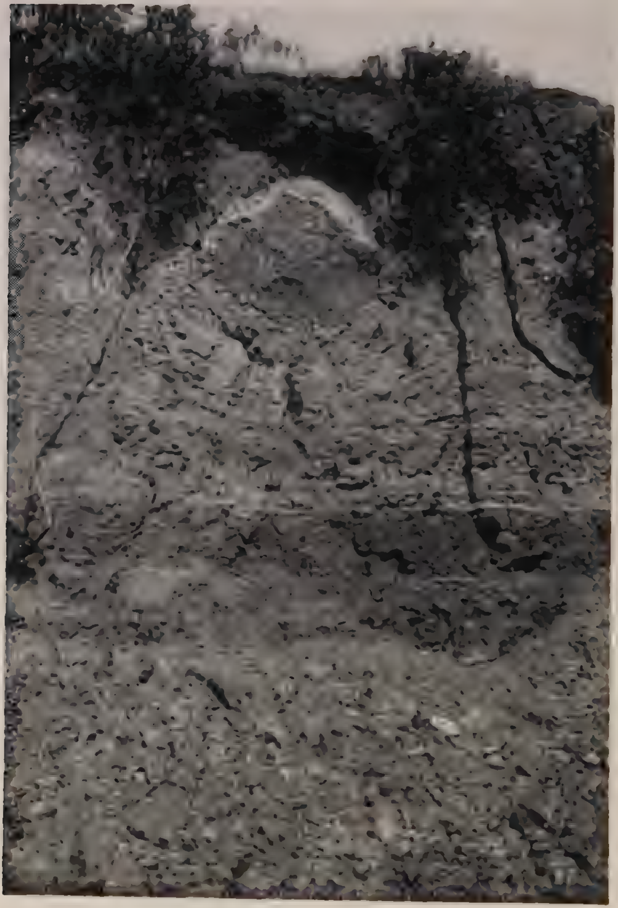


Fig. 2. Approximately same site as Fig. 1 in 1952

[*To face p.* 24



Harkstead Cliff showing displacement of London Clay by stony brickearth forced into it from behind the section

THE STUTTON BRICKEARTH, SUFFOLK

By H. E. P. Spencer, F.G.S.

[*Received* 22 *August* 1952]

ATTENTION became focused on the brickearth at Stutton Ness, on the Suffolk bank of the Stour Estuary, following excavations higher up the river in 1935 at Brundon, near Sudbury, where a similar molluscan fauna and a rich assemblage of mammalian remains suggested the possibility of correlation (Hopwood & Moir, 1939).

Mr. J. Reid Moir began investigations largely to establish the age of flint artefacts which were apparently washed from the brickearth. These, he thought, might be of Upper Palaeolithic age because they resembled implements found in the Dales Road Brickfield at Ipswich (Moir, 1922). Similar implements occurring in identical circumstances were found at Pond Hall, Ipswich, in the subsoil above the brickearth and were dated by a broken polished flint axe discovered *in situ*. Subsequently a Neolithic flint arrow-head was discovered above the brickearth at Stutton, confirming the Pond Hall find. Since these finds were made, Professor F. E. Zeuner (1951) showed that the Dales Brickfield artefacts were also of Neolithic age.

The brickearth at Stutton occupies a hollow in the London Clay and a river-cliff exposes a section half a mile in length, varying from 10 to 20 ft. in height. At each end of the section, the brickearth passes into a stony mass, mapped as gravel, in which included boulder-like masses of London Clay have been observed. The deposit appears to transgress into all the minor valleys and may be seen in road-side banks at Flatford, Tattingstone and at Erwarton, up to about 50 ft. O.D. At Wrabness, on the south side of the Stour, it is again in contact with the London Clay, where remarkable evidence of pressure is exhibited in the section. Here some of the stony material has been squeezed into the joints of the London Clay, while the more compact clay has been displaced laterally and a wedge-shaped mass projects beyond the general level of the cliff-face with beautiful slickensided surfaces. In 1948, the Wrabness cliff revealed an almost vertical contact (sigmoid curve) of brickearth against London Clay; a specimen of the London Clay with slickenside surface is preserved n the Ipswich Museum.

It is usual where this brickearth is in contact with older rock to find evidence of pressure and, at Stutton Ness, Pond Hall (Spencer, 1951*a*), and Broke Hall, the sections are contorted as if by solifluction. At the atter site, the London Clay has been pressed up into the brickearth forming hree reversed and flattened 'c's.

Until recent years, the 500-yd. long cliff at Harkstead has seemed to be all London Clay, with a zone of septaria or cement-stone about 12 ins.

thick at a height of 4 to 6 ft. In places there was a thin capping of gravel which erosion has since shown to be the stony flank of another mass of brickearth. Photographs taken in 1950 by Mr. Hallam Ashley showed large, more or less spherical, boulder-like masses of stones forced into the London Clay, the original horizontal bedding forming concentric curves round them (Plate 5). Other evidence of pressure may be seen in two faults in the cementstone zone, one of which has a displacement of about 4 ft. These rounded masses have since been removed by erosion and now the upper part of the cliff consists of a gravelly deposit with London Clay inclusions. From the evidence of other sites, this gravel will prove to be the stony margin of the brickearth now exposed at the eastern end of the cliff, which, although much contorted, is largely stoneless. The brickearth exposed on the foreshore has so far yielded no Mollusca, but mammalian remains have been collected, *Elephas* sp. and *Bos* or *Bison*, etc. (Spencer, 1951*b*).

The Stutton section had been noted for about a century and a quarter in literature for its Mollusca, but little or no notice was taken of the mammalian fauna, and doubtless much interesting and valuable material has been lost to science. In the Ipswich Museum are a few bones of *Elephas*, *Rhinoceros* and *Cervus* collected in the former brickyard at Holbrook, but there is no data regarding their occurrence. Vertebrate fauna includes fish, two species of birds, at least two species of microtine bones and teeth (the smaller probably *Microtus anglicus* Hinton, the larger *Arvicola* sp.), *Elephas primigenius* Blumenbach, *E. antiquus* Falconer—the narrow toothed variety similar to that figured by Leith Adams (1877, pl. 2, fig. 2); this variety occurs also in a similar brickearth at East Mersea, Essex—*Rhinoceros* sp. (probably *R. leptorhinus* Cuvier), *Bos* or *Bison*, *Equus* sp., *Cervus megaceros* Hart, *C. elaphus* Linn., *Sorex* sp. and *Felis* sp. (wolf and bear occur at Brundon).

It is curious that *Hippopotamus* has been found well inland in Suffolk and is abundant at East Mersea, but no evidence has been recorded of it in the Stutton–Ipswich area. Elephant bones, etc., were formerly common at Wrabness, but are rarely found now as there is little active erosion at present. An os lunare, probably of *E. antiquus*, was recently discovered at the extreme western end of the cliff.

In the Stutton Cliff, the upper part is mainly sandy brickearth with comparatively rare vertebrate fossils, but in 1951 the shaft of a femur of a very young elephant was found close to the top of the section. There are two patches with molluscan fauna and, in washing for these, fossils of calcareous algae are discovered, also sometimes lumps of 'race'. From the stony flanks, which rest against isolated masses of London Clay (perhaps the remnants of islets), a stratum of gravel dips below the beach-level at the eastern end. In 1948, on the occasion of the excursion of the

XVIII International Geological Congress, a much crushed tusk of *Elephas primigenius* was visible in a very ferruginous patch of this gravel. Below the gravel the brickearth is more argillaceous and richer in fossils. An area on the foreshore, much the richest in Mollusca, yielded in one afternoon a scapula, calcaneum, patella and vertebra of an elephant; no other bones of this animal have since been found here. From this site came the avian and microtine remains. The *Equus* bones seem to be confined to the western end of the cliff, where a fine left antler of *Cervus elaphus* Linn. was collected and presented to the Ipswich Museum by Mr. Clavering Fison, the owner of the estate; the rear portion of the skull was discovered by Mr. Reid Moir. Judging from the fresh fractures of this specimen it was undoubtedly buried complete.

A number of erratics, mainly bunter pebbles and vein-quartz, are washed from the brickearth, contributing evidence that the deposit was laid down in a freshwater lake of interglacial age which had a stony shore. Had it been a river deposit, some evidence of current bedding might have been expected. No sign of damming by a moraine has been observed in either the Orwell or Stour Estuaries. Thos. Belt (1877) contended that if ice blocked the northern part of the North Sea, the southern part would eventually become a nearly freshwater inland sea, the overflow from which initiated the Dover Straits. If evidence substantiating this could be discovered, then also would the conditions required for the formation of these brickearths be provided. The fauna indicates a Great Interglacial age for these deposits, and, if at the close of this stage the waterlogged lake mud became frozen, considerable lateral pressure would be exerted against the containing rock. Subsequently the frozen mass moved in its bed, perhaps after melt-water had eroded or deepened the valley now occupied by the estuary, leaving the brickearth deposits temporarily as hanging valleys. In the Orwell Valley there is known to be a buried channel at least 70 ft. deep, and it is highly probable that such a channel exists below the Stour; thus it seems certain that hanging valleys were a feature of that stage of the development of the landscape.

From the many dredgings in the Orwell, which is much used for navigation, considerable light has been thrown on the filling of the buried channel, and while in the Stutton deposit and at Brundon remains of two elephants, *E. antiquus* and *E. primigenius*, occur, only the latter has been found in these dredgings. This may indicate a late interglacial age for the infilling of the channel in which the remains of red deer are also very abundant.

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ON THE OCCURRENCE OF PLEISTOCENE MOLLUSCS AT STUTTON NESS, SUFFOLK

By A. G. Davis, F.G.S.

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THE river cliff section at Stutton was first described by Searles V. Wood in 1834 when he recorded twenty-eight species of land and freshwater Mollusca including the characteristic Pleistocene bivalve *Corbicula fluminalis* (Müller), which he figured and described as *Cyrena trigonula.* John Morris (1838, p. 549) later added nine new records to the molluscan fauna, and, in 1856, S. V. Wood increased the list to forty-two species.

A. S. Kennard and B. B. Woodward (1922, pp. 132–4) made further collections and published a revised list of fifty-four species. D. Kimball (1945, pp. 269–73) worked the section very thoroughly and recorded seventy-two species, thirty-five of this total being terrestial forms.

The writer visited the section in 1951 and noticed that large quantities of the valves of *Corbicula fluminalis* occurred loose on the beach, in association with recent *Cardium edule* Linné, *Mya* sp. and other shells. Not only were they of larger size but also of a tougher consistency than the shells in the cliff-section; they offered considerable resistance to wave-action, whereas those in the cliff were quite fragile.

On reporting the matter to Mr. H. E. P. Spencer, the writer was informed that Mr. Kimball had noticed this occurrence in 1942, when the presence of a lower and more richly fossiliferous level, which yielded to him sixty-three species of Mollusca, was confirmed by trial holes.

On the occasion of the Field Meeting (see p. 24), our arrival at the section was timed for low water and, at this level, small patches of brickearth had been washed clear of sand and beach material, and the following were collected *in situ: Corbicula fluminalis* in quantity, and more rarely *Potomida* (*Unio*) *littoralis* (Cuvier), *Unio tumidus* Retzius, *Arianta arbustorum* (Linné) and *Cepaea nemoralis* (Linné).

The shells in the lower bed are much more plentiful and, in the case of *Corbicula fluminalis*, better preserved and larger (height 31 mm., breadth 35 mm.). The largest known English examples (height 33 mm., breadth 37 mm.) are from Crayford, Kent (Kennard, 1944, p. 152).

The fauna of the lower horizon has not been collected sufficiently to make a comparison with the better-known upper level, but fifty-seven species have been determined, all of which occur also in the upper level.

So far, only three species have been found in the lower bed which have not been recorded from the cliff-section: *Vitrina pelucida* (Müller), one example: *Aplexa hypnorum* (Linné), one example, and an apex of *Lymnaea stagnalis* (Linné).

as suggested by Prof. Allen. It supports the contention that shallow, fresh-water conditions obtained during the period. In the absence of field-evidence it is not advisable to suggest that this soil-bed covers an area comparable in size to the Brede Bed (Allen, 1941) at the base of the Wadhurst Clay. It is hoped that the area over which the bed is known definitely to occur may be extended by its discovery elsewhere at this horizon.

I wish to acknowledge help and encouragement given by Mr. G. S. Sweeting, of the Imperial College of Science and Technology, and by Prof. P. Allen, of the University of Reading.

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EARLY GYPSUM IN THE PERMIAN EVAPORITES OF NORTH-EASTERN ENGLAND[1]

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[*Received* 4 *January* 1952]

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ABSTRACT.—Pseudomorphous structures in borehole cores suggest that much of e basal anhydrite of the Yorkshire evaporite beds was originally deposited as ypsum. Above the basal anhydrite, halite–anhydrite zones, containing layers with seudomorphs after gypsum, are interpreted as transition zones laid down when easonal variations in temperature caused alternate deposition of primary gypsum ith halite and primary anhydrite. Above these transition zones, the calcium sulphate as apparently deposited as anhydrite. All the early gypsum has since been converted anhydrite and halite, perhaps partly by contemporaneous metasomatism by superatant brines, and partly by increase of temperature due to burial beneath a thick over of later sediment.

1. INTRODUCTION

WHETHER the thick deposits of anhydrite found in salt deposits were originally deposited as anhydrite or as gypsum, is a question which as been debated by geologists for many years. Early experimental work n the system $CaSO_4$-H_2O was carried out by Van't Hoff and his co-workers 1912, and earlier papers), but later researches have shown that the results ust be considerably modified. This work has been summarised by osnjak (1938) in a re-investigation of the system $CaSO_4$-HO_2, and was ollowed (1940) by a study of the stability relationships of gypsum and nhydrite in solutions of sea salts at 30°C.

From these studies, Posnjak concluded that, in the system $CaSO_4$-H_2O, e transition point gypsum–anhydrite lies at 42°C. Gypsum is truly etastable between this temperature and 97°C., the latter being at the tranition point gypsum–hemihydrate. Between these temperatures, gypsum an change to anhydrite by solution of gypsum and crystallisation of nhydrite round pre-existing anhydrite nuclei. The transition temperature ypsum–anhydrite is lowered considerably when other salts are present, nd in the evaporation of sea-water at 30°C., it would be expected that

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[1] I am most grateful to the Anglo-Iranian Oil Company and to Fisons Limited, for permission publish results based on study of material from their borings, and to the Durham Colleges for eir research grant.

gypsum would commence crystallising when the salinity had reached 3.35 times the normal salinity of sea-water, and anhydrite at 4.8 times the normal salinity. With complete evaporation, rather less than half the calcium sulphate originally present would be precipitated in the form of gypsum, and the rest as anhydrite.

When we turn to the literature on actual anhydrite deposits, we find no real agreement on this question. Some geologists assume that much of the anhydrite was deposited as gypsum and later converted to anhydrite. Others point out that there is practically no evidence of early gypsum to be seen in the rocks, and consider that the lack of disturbance of finely banded structures indicates that the primary mineral was anhydrite.

2. EARLY GYPSUM IN THE BASAL ANHYDRITE OF THE POTASH FIELD

Evidence of the presence of early gypsum in the three Permian evaporite beds passed through by the Eskdale No. 2 boring, near Whitby, has been given by the writer (Stewart, 1949, 1951a, 1951b). This evidence was restricted to the halite–anhydrite zones (invaded by later polyhalite in the Lower Evaporite Bed), above the main basal anhydrite layers. Armstrong, Dunham and others (1951) have indicated that similar evidence extends to other parts of the potash-field and have also given evidence of early gypsum in the Carnallitic Marls, the clays between the Upper and Middle Evaporite Beds. Halite–anhydrite pseudomorphs after gypsum have been recorded from similar zones in the Texas–New Mexico saltfield (Schaller & Henderson, 1932).

Evidence of early gypsum in the thick massive anhydrite layers of these deposits has not yet been recorded, but such evidence has now been found in material from the Eskdale No. 2 boring, put down by the Anglo-Iranian Oil Company. In 1942, the writer collected a large number of core-samples, which had been lying at the boring site exposed to the weather for three years. Most of these consisted of massive anhydrite–carbonate rocks of the Lower Evaporite Bed (Stewart, 1949). No evidence of early gypsum could be seen in slices of these rocks, but some of the samples showed a curious corded appearance on the weathered surfaces. In order to see whether this curious structure could be accentuated, a number of the samples have been left, since that time, exposed to the weather, and structures have developed which are interpreted as pseudomorphs of anhydrite after early gypsum.

When well developed, the pseudomorphs form closely packed aggregates of anhydrite, normally a quarter to half an inch in length and about an eighth of an inch in width, but sometimes a good deal larger. Most of them are elongated in an approximately vertical direction, but some are arranged in radiate groups. In very rare cases a suggestion of swallow-tail twinning is seen, but usually the edges of the pseudomorphs are rounded and indistinct. In many cases the pseudomorphs are distorted, and all stages of deformation and flattening can be seen, until the structures become barely detectable.

These pseudomorphous structures cannot be detected on fresh surfaces of these samples, nor can they be seen in thin section. The samples consist, when fresh, of anhydrite of fine to medium grain with small quantities of magnesite or dolomite. Recrystallisation textures are common, often indicating recrystallisation of anhydrite at more than one period. A little secondary gypsum is often present near the weathered surfaces, but the surface-structures are not due to growth of large gypsum crystals on weathering, since the gypsum forms small grains, often fibrous, lying in various orientations.

It seems reasonable to suppose that these structures are inherited from previous gypsum crystals and that the gypsum was primary. A large number of the weathered samples show these structures, and it appears likely that a very considerable quantity of the massive anhydrite of this evaporite bed was originally deposited as gypsum.

It may be noted that the fibro-radiate anhydrite-dolomite-rock, found near the base of this evaporite bed (Stewart, 1949, p. 641), does not show these structures when weathered. This rock may have been formed by late replacement of the basal dolomite by anhydrite.

3. EARLY GYPSUM IN THE HALITE–ANHYDRITE ZONES OF THE POTASH FIELD

According to the experimental evidence, a stage would be reached during the formation of these evaporites at which the increasing salinity would allow the deposition of primary anhydrite. A basal layer of gypsum should give place upwards to anhydrite and halite. In the main halite zones of the Yorkshire evaporite beds, the anhydrite present shows no pseudomorphous structures suggestive of early gypsum, and the calcium sulphate may well have been deposited as anhydrite. Below the halite zones and above the basal anhydrite, there are the layered halite–anhydrite zones containing the well-developed halite–anhydrite pseudomorphs after gypsum which have been recorded in the literature mentioned above. It is empting to regard these layered zones as transitional, formed when slight differences in temperature and salinity would cause differences in the nature of the primary calcium salt.

The petrography of these zones has been discussed in earlier papers e.g. Stewart, 1951a, p. 459) but, since at that time there was no direct evidence that the basal anhydrite was derived from gypsum, no convincing interpretation of the observed layering was given. The repeated upward succession of thin layers—anhydrite (with carbonate)–gypsum–halite—was recorded as an apparently primary succession, accompanied by the development of secondary gypsum at the expense of earlier anhydrite, and secondary halite and anhydrite at the expense of earlier gypsum.

More complete recent material from the boreholes put down by Fisons, Ltd., at Robin Hood's Bay (F.1 borehole) and Staintondale (F.2 borehole), has shown that the original succession was of the following type: anhydrite–gypsum–gypsum with halite–gypsum–anhydrite; the early gypsum being now represented by pseudomorphs consisting of anhydrite and halite. Carbonate is present, chiefly associated with anhydrite; and secondary gypsum apparently developed in the unconsolidated anhydrite–carbonate mud below adjacent primary gypsum layers. Units of the above type are repeated and form a layered series; the individual layers varying from a fraction of an inch to six inches or so in thickness. Often the units are incomplete, and several layers may be missing.

Periodic differences in salinity, due, for example, to periodic flooding, would give rise to the sequence gypsum–anhydrite–halite. However, seasonal variations in temperature may explain the observed sequence. It has been suggested that, in accordance with the temperature coefficients of solution of the minerals, the alternation of halite and anhydrite layers in some salt deposits is due to seasonal variation in temperature (e.g. D'Ans, 1949, p. 298)—halite being deposited in cold seasons and anhydrite in hot, to give a series of annual layers. Seasonal temperature variation would be very considerable during the evaporation of a relatively shallow body of water under arid conditions, and it is possible that over quite a long period of time, annual layers of gypsum and anhydrite would form when the temperature fluctuated above and below the transition point gypsum–anhydrite. A stage in evaporation would be reached at which anhydrite would be deposited during the hot summer, gypsum during the cooler spring and autumn, and halite with some gypsum during the winter.

This would give the observed sequence. Some solution or metasomatism of earlier layers by the brines which deposited the adjacent later ones, would explain the observed cases of incomplete sequence and development of secondary minerals. Evidence of widespread metasomatism of this type has been discussed (Stewart, 1951a).

A basal layer of gypsum, then, would be followed by a series of rocks containing anhydrite, gypsum and halite, and these would be deposited until the increasing salinity inhibited deposition of gypsum in spite of the temperature variation.

In the Upper Evaporite Bed, material from F.1 and F.2 borings shows that layers containing gypsum pseudomorphs alternate with anhydrite layers throughout the basal anhydritic zone. Halite is present in most of the pseudomorphous layers. Their appearance near the base of the evaporite bed suggests that in these localities this third evaporation cycle started from a relatively concentrated brine. This is also indicated by the presence of only a very thin carbonatic layer (about three feet of mixed carbonate and anhydrite) at the base of this bed. It may be of significance that the main carbonate in this anhydrite zone is magnesite, as compared with the dominant dolomite near the base in the other two evaporite beds of this region.

In these borings, the pseudomorphs after gypsum in the Upper Evaporite Bed have been invaded by rinneite, carnallite and sylvine, apparently from below. This is a late change, associated with veining in the Carnallitic Marls, and will be discussed in a later communication.

In the Lower Evaporite Bed, polyhalite is a major constituent, and appears to have formed in the halite–anhydrite zone as a secondary mineral after the change gypsum $\geqslant$ anhydrite and halite. Since the latter change may have been due to contemporaneous metasomatism, it does not help us to date the appearance of polyhalite. However, it appears that in the Eskdale No. 3 boring (Armstrong, Dunham *et al.*, 1951), polyhalite has replaced part of the lower halite zone and part of the upper anhydrite zone, while in the Eskdale No. 2 boring (Stewart, 1949) it has replaced parts of the lower anhydrite and lower halite zones. This apparent change in level of the secondary polyhalite may mean that the replacements were late ones, but more borings are needed to settle this point.

4. THE OUTLYING PARTS OF THE SALTFIELD

In the parts of the saltfield outside the potash-bearing area, the only recorded evidence of early gypsum is that from the Hayton boring, where anhydrite pseudomorphs after gypsum occur in anhydrite-rock (Stewart, 1951b, p. 571). Though there is plenty of evidence of late gypsum replacing anhydrite, Dunham (1948) found no evidence of pre-anhydrite gypsum in material from the outer part of the saltfield. Dunham has pointed out that the anhydrite normally forms aggregates of mutually interfering grains, suggesting that crystallisation was completed after crystal accumulation on the sea-floor, or that there has been bulk recrystallisation of anhydrite. Recrystallisation textures are certainly extremely common, and recrystallisation would tend in many cases to destroy evidence of pseudomorphous tructures. If a large mass of gypsum were converted to anhydrite, later compaction, with the squeezing out of interstitial liquid, due to tectonic forces or to a heavy load of sediment, would probably destroy evidence of pseudomorphs except in special cases. If an original fine-grained deposit of gypsum were converted to anhydrite, no trace of the original mineral need be expected. Bulk replacement of anhydrite by polyhalite, for example, of the type recorded by Schaller & Henderson (1932), if carried to completion, would probably leave no recognisable trace of anhydrite, and original bedding-structures would be preserved in the distribution of carbonate and detrital material.

In fact, although there is no direct evidence of early gypsum in the outlying part of the saltfield, except at Hayton, the writer is inclined to think that gypsum was a primary constituent here, as in the central potash-bearing region.

5. CONVERSION OF PRIMARY GYPSUM TO ANHYDRITE

All the original gypsum in these deposits has since been converted to anhydrite and halite. This change might have been effected in two ways: firstly, by metasomatism by supernatant brines during the formation of the evaporites, or secondly, by increase in temperature due to burial beneath a thick cover of sediments. The relative lack of distortion of the pseudomorphs in the halite–anhydrite zones, would suggest that the change here might well be due to the first cause. In many cases the gypsum has been replaced by an outer zone of anhydrite and an inner one of halite, and it is possible that the contraction of volume in the gypsum–anhydrite replacement has left cavities in which halite has been deposited.

A thick basal layer of gypsum, however, would be less likely to be converted to anhydrite by contemporaneous metasomatism. The transition temperature gypsum–anhydrite would be exceeded with even a moderate thickness of cover. Temperature measurements in the E.2 boring (Lees and Taitt, 1946) gave 107.1°F. at 4200 ft. depth (a surprisingly low figure), and, in the F.1 boring, 94°F. at 2600 ft. depth. The transition temperature must have been passed in the Yorkshire deposits. Primary anhydrite nuclei would presumably exist at the top of the gypsum layer, and would enable the replacement of gypsum by anhydrite to proceed slowly downwards to the base, the gypsum dissolving in any interstitial fluid and anhydrite being deposited. The change would release a large quantity of water, and most of this and of any original interstitial fluid must have been pressed out of the evaporites at some stage, since in the main these deposits are nearly free from fluid. The abundant evidence of distortion of pseudomorphs observed in the massive anhydrite would be expected. Water released in this way would perhaps be available to cause widespread metasomatic effects in other parts of the deposits, as advocated by many continental salt geologists.

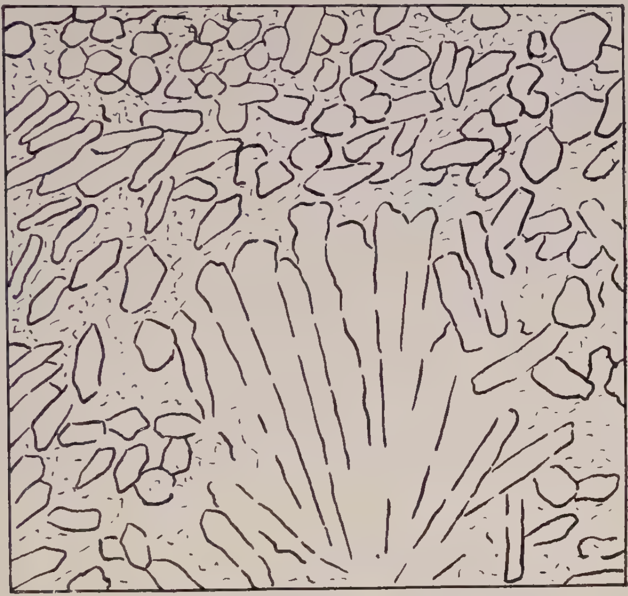

Fig. 1. Weathered surface of anhydrite core

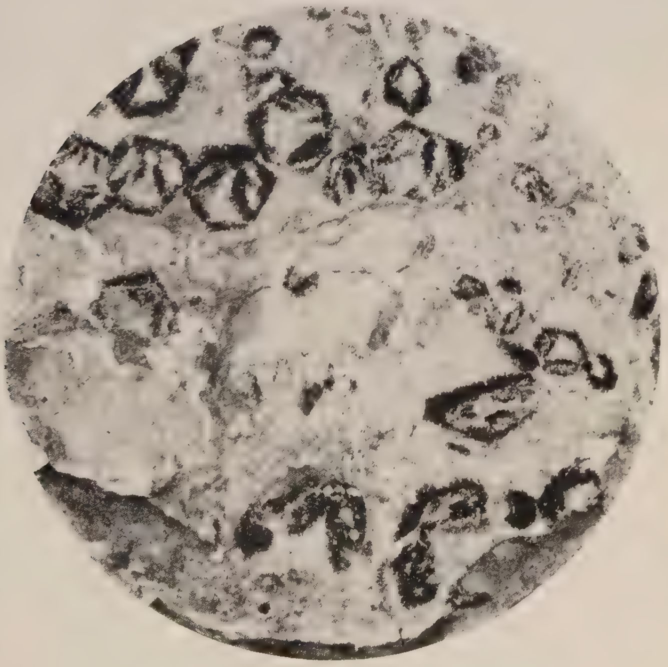

Fig. 2. Cross-section of core from anhydrite zone

PSEUDOMORPHS AFTER EARLY GYPSUM IN
YORKSHIRE EVAPORITES

EXPLANATION OF PLATE 6

Fig. 1. Weathered surface of anhydrite core from the Lower Evaporite Bed, Eskdale No. 2 boring. The whole consists of fine-grained anhydrite with a few grains of carbonate. Weathering has brought out structures interpreted as pseudomorphs after gypsum. A radiate group of these pseudomorphs is seen near the centre, and cross-sections of pseudomorphs occur towards the top of the figure. The structures are present on weathered cross-sections of the core as well as on the outer surfaces, and so cannot be due to scoring of the surface during drilling. Approx. 4600 ft. below surface. 2 diam.

Fig. 2. Cross-section of core from anhydrite zone of Upper Evaporite Bed, Robin Hood's Bay boring, showing six-sided cross-sections of pseudomorphs after early gypsum, in a matrix of anhydrite with magnesite. The pseudomorphs consist of anhydrite (grey) and halite (black). 3358 ft. below surface. Nat. size.

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THE ANNUAL REPORT OF THE COUNCIL OF THE GEOLOGISTS' ASSOCIATION FOR THE YEAR 1952

THE numerical strength of the Association on 31 December 1952, was as follows:

Honorary Members	20
Ordinary Members:	
Life Members (compounded) ...	185
Annual Subscribers	1809
	2014

During the year 111 new members were elected, and the Association lost 139 members through death, resignation and removals under Rule XI for failure to pay subscriptions.

Thus, the membership has suffered a net loss of twenty-eight, the first time a decrease in membership has been recorded since 1941.

The list of deceased members is as follows: W. Baynes Smith, Miss K. C. Boswell, C. E. N. Bromehead, W. E. Browne, G. A. Burnett, Miss M. C. Crosfield, D. E. Finlay, L. Guillaume, G. A. Longden, R. W. Marston, F. W. H. Migeod, J. V. Ramsden, Mrs. D. V. Stebbing, H. R. Sykes, R. Wallace, G. R. Willan and H. Woods.

Obituary notices are published on page 59.

FINANCE

On the Income side of the General Purposes Account, admission fees and annual subscriptions show a revenue of £1488 10*s*. 0*d*. as compared with £988 10*s*. 0*d*. in 1951. On the expenditure side of the account, the cost of four parts of the PROCEEDINGS (354 pages) appears as £1344 19*s*. 5*d*. as compared with £1096 7*s*. 11*d*. in 1951. The cost of printing *Monthly Circulars* is £139 5*s*. 6*d*. as compared with £178 1*s*. 3*d*. in 1951. It was thought undesirable to make any transfer from the Compounding Fund in view of its increased liability consequent upon the increase in the Annual Subscription. Costs continue to rise, therefore the Annual Allocation for the Reserve Fund for Index and List of Members has been increased from £40 to £100. The accounts show that the increase of the annual subscription was an imperative necessity.

Special attention is directed to the item in the Balance Sheet 'Annual Subscriptions in Arrears'. The Council is seriously concerned at the increase in the number of unpaid subscriptions and calls the attention of Members to the fact that the sending out of reminders adds to the clerical work of the Honorary Treasurer and incurs an unnecessary expenditure of the Association's funds.

The Association is grateful to Professor and Mrs. W. G. Fearnsides for the gift of £115 6*s*. 6*d*., the proceeds of the sale of the late Professor Watts's book, 'The Geology of the Ancient Rocks of Charnwood Forest', together with the remaining stock of the book which will be sold by the Association. The Council decided to place this sum and proceeds of future sales in a special fund to be known as the Watts Charnwood Forest Fund.

An unconditional legacy of £100 from the late G. R. Willan is gratefully acknowledged and has been added to the Bequest Funds.

The Council of the Royal Society has continued to help us by an allocation of £250 from the Parliamentary Grant in Aid of Scientific Publications.

PUBLICATIONS

Publications Committee. The Committee consisted of the Officers (seven) and Mrs. J. M. Eyles, Mr. T. Eastwood, Dr. A. F. Hallimond, Dr. G. H. Mitchell and Dr. H. Dighton Thomas. Mr. H. A. Hayward, O.B.E., retired from the office of Publications Secretary on 1 September 1952, and was succeeded by Dr. W. E. Swinton.

The Committee met on seven occasions and considered twenty-five papers, on which reports were made to the Council.

Proceedings. It has been possible to issue all four parts of Volume 63 during the year. The number of pages was 354, an increase of seventy-six on the previous volume.

MEETINGS

Nine Ordinary Meetings were held at which two papers were read, six papers were 'taken as read', and five lectures were given.

The thanks of the Association are due to the authors and the lecturers and to the Geological Society for the use of its Apartments throughout he year.

REUNION

The Annual Reunion was held at Bedford College for Women on Saturday, 8 November. Many interesting exhibits were shown and it was attended by about 300 members and friends.

Thanks are due to the College Authorities and the staff of the Geology Department.

FIELD MEETINGS

The Committee consisted of the Officers (seven) and Mrs. Hawkes, Messrs. N. F. Hughes, W. Pitcher, B. Ainsley, A. G. Davis, L. J. Pitt, J. F. Hayward, J. F. Kirkaldy, Vernon Wilson and B. C. Worssam. On 1 September, Mr. S. W. Hester was appointed Field Meetings Secretary to succeed Dr. T. Barnard, who resigned.

During the year there were three demonstrations and eight whole day field meetings. The Easter, Whitsun and Summer Long Field Meetings were held at Oxford, Derbyshire and South Shropshire respectively. A week-end meeting to Norfolk was cancelled owing to lack of support.

The thanks of the Association are due to the directors and all others who organised and assisted at these meetings.

THE LIBRARY

The Library Committee consisted of the President, Mrs. H. K. Hawkes, Dr. L. R. Cox, Messrs. R. V. Melville, R. Reeley, C. D. Ovey, C. W. Wright and J. Wilks, Librarian of University College. Thanks are due to the donors of a number of books and pamphlets, listed on page 58. The following have been added to the exchange list:

North Staffordshire Field Club.
Institute for Geology and Subsurface Research, Athens, Greece.
Geologisch Bureau voor het Mijngebied, Heerlen, Holland.
Slovene Academy of Sciences and Arts, Ljubljana, Jugoslavia.
Geolosko Rudarski Institut, Zagreb, Jugoslavia.

The following has been deleted from the list:

National Geological Survey of China.

NORTH-EAST LANCASHIRE GROUP

Chairman: J. Ranson, A.M.I.M.E., F.G.S.

Secretary: D. H. Learoyd, B.Sc., F.G.S.

Committee: Mrs. Harrop, B.A., B.Sc., N. Thompson, G. F. Urry, I. A. Williamson.

During the year six lectures and four field meetings were held. Particulars are published in the Report of the Session, p. 49. Thanks are due to the Authorities of the Blackburn Technical College for the use of rooms.

MIDLAND GROUP

Chairman: A. J. Aiers.

Secretary: Miss Grace M. Bauer.

Committee: Miss B. M. E. Dudley, Messrs. G. Cotton, B.Sc., F.G.S., E. D. Lacy, F.G.S., H. Sanders, W. Waldron.

During the year five meetings were held in the Geology Department, The University, Birmingham, and there were four field meetings. Particulars are published in the Report of the Session. Thanks are due to Professor Shotton for the use of the Geology Department at the University for meetings.

NORTH STAFFORDSHIRE GROUP

Chairman: F. Wolverson Cope, D.Sc., F.G.S.
Secretary: T. S. Purcell, B.Sc.
Treasurer and Field Meetings Secretary: J. T. Gleaves, B.A.
Committee: W. J. Adams, R. Barrass, D.F.C., B.A., P. S. Keeling, B.Sc., A.R.S.M., J. Myers, B.Sc., F.G.S., D. O. Thomas and J. T. Wattison.

During the year six meetings were held at the Arts Centre, Newcastle-under-Lyme, one meeting in the Geology Department of the University College of North Staffs and there were two field meetings. Details are published in the Report of the Session. Thanks are due to the Authorities of the Arts Centre and to the University College of North Staffs for the use of rooms.

TRUSTEES

The Trustees of the Association are:

Managing: Mr. S. Hazzledine Warren, F.G.S., Dr. W. F. Fleet, M.Sc., A.R.I.C., A.C.P., F.G.S. and Mr. E. C. Martin, O.B.E., B.Sc., A.R.I.C., F.G.S.

Custodian: The Royal Bank of Scotland, Western Branch.

FOULERTON AWARD

The Foulerton Award for the year was given to Mr. E. C. Martin, O.B.E., B.Sc., A.R.I.C., F.G.S., in recognition of his services to Geology and the Association.

HOUSE LIST

Mr. A. G. Bell retires as Senior Vice-President and Miss M. A. Arber, Mr. W. Dack and Dr. J. F. Kirkaldy as Ordinary Members of the Council. Mr. A. Wrigley retires from the Office of Treasurer owing to ill health. Thanks are due to these members for services rendered to the Association.

Dr. L. R. Cox retires from the office of Librarian and merits the thanks of the Association for service as Librarian for the past thirteen years.

ACCOUNTS FOR THE YEAR ENDING 31 DECEMBER 1952

GENERAL PURPOSES ACCOUNT

EXPENDITURE

	£	s.	d.	£	s.	d.
By PROCEEDINGS of the Association:						
(1) Printing	1022	17	11			
(2) Illustrations	263	15	0			
(3) Authors' separate copies	58	6	6	1344	19	5
,, Printing *Monthly Circulars*				139	5	6
,, Stationery				113	3	5
,, Expenses at Meetings				36	17	0
,, Expenses at Field Meetings				6	14	5
,, Addressing and Stock-keeping				26	12	7
,, Postages				196	17	1
,, Insurance				2	2	0
,, Incidental Expenses				9	15	11
,, Transfer to Reserve Fund for Index and List of Members				100	0	0
,, Clerical Assistance to Treasurer and Accountancy ...				56	10	0
,, Excess of Income over Expenditure for the Year ...				89	17	5
				£2122	14	9

INCOME

	£	s.	d.	£	s.	d.
To Admission Fees:						
Received for 1952 Elections	46	0	0			
Received for arrears	17	10	0			
	63	10	0			
Less Arrears at 31 December 1951, £25 10, estimated to realise	15	0	0			
	48	10	0			
Add Arrears at 31 December 1952, £8, estimated to realise	5	0	0	53	10	0
To Annual Subscriptions:						
(1) Received in 1948, 1949, 1950 for 1952 ...	5	0	0			
(2) Received in 1951 for 1952	89	10	0			
(3) Received in 1952 for 1952	1184	10	0			
(4) Received in 1952 for arrears	56	0	0			
	1335	0	0			
Less Arrears at 31 December 1951, £138, estimated to realise	100	0	0			
	1235	0	0			
Add Arrears at 31 December 1952, £554 10, estimated to realise	200	0	0	1435	0	0
To Royal Society Grant:						
1951	150	0	0			
1952	250	0	0	400	0	0
,, Sale of Publications				154	14	9
,, Miscellaneous Receipts				4	10	0
,, Transfer from other Accounts:						
Illustrations Fund				75	0	0
				£2122	14	9

BALANCE SHEET AT 31 DECEMBER 1952

LIABILITIES

	£	s.	d.	£		d.
To Annual Subscriptions Received in Advance:						
In 1948 for 1953/54	1	0	0			
In 1949 for 1953/54	1	0	0			
In 1950 for 1953/54	2	0	0			
In 1951 for 1953	2	10	0			
In 1952 for 1953	84	10	0	91	0	0
„ Sundry Creditors:						
Messrs. Benham & Co. Ltd.	55	0	0			
Messrs. Martin Farlow & Co.	31	10	0	86	10	0
„ Special Funds:						
Illustrations Fund	27	17	1			
Illustrations Fund (Capital)	20	0	0			
Reserve Fund for Index and List of Members	141	2	3			
Compounding Fund	1814	11	7			
Bequest Funds	910	3	8			
General Reserve Fund	329	0	0			
Watts Charnwood Forest Fund	127	4	6	3369	19	1
„ Accumulated Funds at 1 January 1952	124	19	6			
Add Excess of Income over Expenditure for the year	89	17	5	214	16	11
				£3762	6	0

ASSETS

	£	s.	d.	£	s.	d.
By Investments (Special Funds) at cost or value when acquired:						
„ Bequest Funds:						
£143 8 9 3½% War Stock	141	14	0			
£150 New Zealand 3½% Stock 1960/64	122	5	0			
£285 3% Defence Bonds	285	0	0			
£100 3% Savings Bonds 1960/70	100	0	0	648	19	0
„ Compounding Fund:						
£1217 2 6 Nottingham Corporation 3% Irredeemable Stock	1152	13	2			
£200 3% Savings Bonds 1955/65	200	0	0			
£170 3½% War Stock	152	14	5			
£100 3% Savings Bonds 1965/75	100	0	0	1605	7	7
„ Illustrations Fund (Capital):						
£21 0 10 Metropolitan Water Board 3% B Stock				20	0	0
„ Annual Subscriptions in Arrears:						
£554 10 estimated to realise				200	0	0
„ Admission Fees in Arrears:						
£8 estimated to realise				5	0	0
„ Cash at Bankers and in Office:						
At Bankers	135	8	5			
In Office	51	18	6	187	6	11
„ Special Funds:						
Illustrations Fund at Bank	27	17	1			
Compounding Fund at Bank	209	4	0			
Reserve Fund for Index and List of Members at Bank	141	2	3			
General Reserve Fund	329	0	0			
Bequest Fund at Bank	157	9	2			
Bequest Fund in Post Office Savings Bank	103	15	6			
Watts Charnwood Forest Fund:						
At Bank	10	11	9			
At Post Office Savings Bank	116	12	9	1095	12	6
				£3762	6	0

SPECIAL ACCOUNTS

ILLUSTRATIONS FUND

	£	s.	d.		£	s.	d.
To Balance in hand on 1 January 1952	57	6	1	By Transfer to General Purposes Account for Illustrations	75	0	0
,, Donations and Subscriptions	44	18	6	,, Balance 31 December 1952, at Bank	27	17	1
,, Transfer from Illustrations Fund (Capital)		12	6				
	£102	17	1		£102	17	1

ILLUSTRATIONS FUND (CAPITAL)

	£	s.	d.		£	s.	d.
To Balance in hand on 1 January 1952	–	–	–	By Transfer to Illustrations Fund...		12	6
,, Dividends as Received		12	6	,, Balance 31 December 1952, at Bank	-	-	-
		12	6			12	6

COMPOUNDING FUND

	£	s.	d.	£	s.	d.		£	s.	d.
To Balance in hand on 1 January 1952				129	14	10	By Balance 31 December 1952, at Bank	209	4	0
,, Composition Fees received during the year				28	0	0				
,, Dividends as received:										
£1217 2 6 Nottingham Corporation 3% Stock	36	10	2							
£170 3½% War Stock	5	19	0							
£300 Savings Bonds	9	0	0							
				51	9	2				
				£209	4	0		£209	4	0

RESERVE FUND FOR INDEX AND LIST OF MEMBERS

	£	s.	d.		£	s.	d.
To Balance in hand on 1 January 1952	230	2	3	By Cost of printing New List of Members	189	0	0
,, Yearly Reservation for 1952	100	0	0	,, Balance 31 December 1952, at Bank	141	2	3
	£330	2	3		£330	2	3

BEQUEST FUNDS

	£ s. d.	£ s. d.		£ s. d.	£ s. d.
To Balance in hand on 1 January 1952		136 0 8	By Balance 31 December 1952, at Bank	157 9 2	
„ Willan Bequest		100 0 0	„ „ „ „ „ in Post Office Savings Bank	103 15 6	
„ Premium on Conversion of Defence Bonds		17 0			261 4 8
„ Dividends as received:					
£143 8 9 3½% War Stock	5 0 6				
£150 New Zealand 3½% Stock	5 5 0				
£285 3% Defence Bonds	8 11 0				
£100 3% Savings Bonds 1960/70	3 0 0				
		21 16 6			
„ Interest on Post Office Savings Bank Deposit		2 10 6			
		£261 4 8			£261 4 8

GENERAL RESERVE FUND

	£ s. d.		£ s. d.
To Balance in hand on 1 January 1952	329 0 0	By Balance 31 December 1952, at Bank	329 0 0
	£329 0 0		£329 0 0

WATTS CHARNWOOD FOREST FUND

	£ s. d.		£ s. d.
To Receipt from G. S. Sweeting	115 6 6	By Balance 31 December 1952, at Bank	10 11 9
„ Sales of Books	11 18 0	„ „ „ „ „ at Post Office Savings Bank	116 12 9
	£127 4 6		£127 4 6

"TRUST" FUNDS

FOULERTON AWARD FUND

	£ s. d.	£ s. d.		£ s. d.
To Balance in hand on 1 January 1952		22 17 0	By Award to Mr. E. C. Martin	10 0 0
„ Dividends as received:			„ Balance 31 December 1952, at Bank	23 6 7
£349 7 British Transport 3% Guaranteed Stock	5 10 0			
„ Income Tax repayments for 1951/52	4 19 7			
		10 9 7		
		£33 6 7		£33 6 7

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND

	£ s. d.		£ s. d.
To Balance in hand on 1 January 1952	72 10 9	By Grant, K. A. Kermack...	25 0 0
,, Income for 1951 (ex Public Trustee)	7 4 10	,, Income Tax repaid to Public Trustee	3 15 10
,, Income Tax repayment for 1951/52	6 11 0	,, Balance 31 December 1952, at Bank	57 10 9
	£86 6 7		£86 6 7

HENRY STOPES MEMORIAL FUND

	£ s. d.	£ s. d.		£ s. d.
To Balance in hand on 1 January 1952 ...		19 17 2	By Lecture Fee Dr. K. P. Oakley ..	15 15 0
,, Dividends as received:			,, Cost of engraving Bronze Medal, Dr. K. P. Oakley	7 10
£265 19 2 Government of Newfoundland 3% Stock, 1943/63	4 3 10		,, Balance 31 December 1952, at Bank	11 13 10
Income Tax repayment for 1951/52	3 15 8			
		7 19 6		
		£27 16 8		£27 16 8

MARTIN FARLOW & CO., *Incorporated Accountants.*

We have compared these statements with the books and accounts presented to us and find them to agree.

We have also verified the investments of £1217 2 6 Nottingham Corporation Stock, £200 3% Savings Bonds, 1955/65, £100 3% Savings Bonds, 1965/75, and £170 3½% War Stock of the Compounding Fund, £349 7 0 British Transport 3% Guaranteed Stock, 1978/88, of the Foulerton Award Fund, £143 8 9 3½% War Stock, £150 New Zealand 3½% Stock, 1960/64, £285 3% Defence Bonds and £100 3% Savings Bonds, 1960/70, of the Bequest Funds; £21 0 10 Metropolitan Water Board 3% B Stock of the Illustrations Fund (Capital), and £265 19 2 Government of Newfoundland 3% Stock, 1943/63, of the Henry Stopes Memorial Fund.

A. WRIGLEY, *Treasurer*

R. BRADSHAW } *Auditors.*
G. WILSON

REPORT OF THE SESSION 1952

Ordinary Meeting, 4 *January* 1952.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Robert Barrass, D.F.C., B.A., Miss Mary Monica Brown, Paul Clifford, Gerald Conroy Dixon, Norman Spencer Fearn, David Cunningham Greig, Frederick Percy Hammond, Michael Robert House, Muhamurad Mahbub-i-Khuda, M.Sc., Deryck James Colson Laming, Md. Abdul Latif, M.Sc., Raymond Seth Leyshon, Brian Lister, Maurice Lock, Derek John Rawlings, Frank Nelson Saxton, Wilfred Brett Watson, Henry Charles Wilks, B.Sc., Robert Bryden Wilson, B.Sc., Michael Allan Wilson, B.A. and Arthur Meredyth Wynne were elected Members of the Association.

Dr. A. F. Hallimond and Mr. R. Bradshaw were elected Auditors of the accounts for 1951.

The following lecture was delivered: 'A preliminary survey of the work of a research team in NW. Donegal', by W. S. Pitcher, Ph.D., B.Sc., F.G.S.

Ordinary Meeting, 1 *February* 1952.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

Peter William Andrews, Jeremy Arthur Heath Counsell, John Chapman Dixon, Richard Michael Cardwell Eagar, M.A., Ph.D., F.G.S., John Raymond Jay, Miss Miranda Frances Kiddle, Nyi Nyi and Robert G. A. Weiss were elected Members of the Association.

The following paper was read: 'Some marginal drainage features of the Chalky Boulder Clay Ice Sheet in Hertfordshire', by Professor S. W. Wooldridge, D.Sc., F.G.S.

The following papers were 'taken as read': (1) 'The Jurassic Rocks of the Lincoln District', by Professor W. David Evans, M.Sc., Ph.D., F.L.S., F.R.G.S., F.G.S., and (2) 'The Pliocene-Pleistocene Boundary in the East of England', by Professor P. G. H. Boswell, O.B.E., D.Sc., F.R.S., F.G.S.

Annual General Meeting, 7 *March* 1952.—Mr. T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., President, in the chair.

The Annual Report of the Council was taken as read. It was moved by Mr. Percy Evans, seconded by Mrs. Eyles, 'That the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for the year 1951'. The resolution was carried *nem. con.*

The President declared the following members duly elected as Officers and Members of Council in accordance with Rule XIII: *President*, G. W. Himus, Ph.D., F.G.S.; *Vice-Presidents*, A. G. Bell, I.S.O., B.Sc., F.G.S., E. Ernest S. Brown, M.B.E., F.G.S., D. Williams, M.Sc., Ph.D., B.E., F.G.S., A. J. Butler, O.B.E., M.Sc., F.G.S., T. Eastwood, A.R.C.S., M.I.M.M., F.G.S.; *Treasurer*, R. W. Pocock, D.Sc., F.G.S.; *Secretaries*, General—R. Reeley, F.G.S.; Field Meetings—T. Barnard, Ph.D., D.I.C., F.G.S.; Publications Committee—H. A. Hayward, O.B.E., F.G.S.; *Editor*, C. D. Ovey, B.Sc., F.G.S., F.R.Met.S.; *Librarian*, L. R. Cox, M.A., Sc.D., F.R.S., F.G.S.; *Twelve other Members of the Council*, B. Ainsley, F.G.S., Miss M. A. Arber, M.A., F.G.S., F.R.G.S., W. Dack, I.S.O., F.G.S., Mrs. H. K. Hawkes, M.Sc., F.G.S., J. F. Kirkaldy, D.Sc., F.G.S., W. S. Pitcher, Ph.D., B.Sc., F.G.S., H. Dighton Thomas, M.A., Ph.D., F.G.S., Miss D. E. Wisden, M.Sc., F.G.S., A. F. Hallimond, M.A., Sc.D., F.G.S., L. J. Pitt, F.G.S., Mrs. V. A. Eyles, B.Sc., F.G.S., E. C. Martin, O.B.E., B.Sc., A.R.I.C., F.G.S.

It was moved by Dr. A. W. Woodland, seconded by Mr. W. H. C. Ramsbottom, and duly carried, 'That the best thanks of the Association be given the retiring President, the Officers, retiring members of Council and the Auditors'.

The Henry Stopes Memorial Medal was presented to Dr. K. P. Oakley in recognition of his work on the prehistory of Man. The President said:

> Dr. Oakley: You have shown by the quality of your work and the volume of your writings on early man that the choice of the Council is indeed justified.
>
> The work, begun in your student days in the Thames Valley, has been extended not only in that area and in Essex but further afield into France, where much research had already been done, and into East Africa. Your interest in the subject was recognised when you were made Secretary to the Committee appointed by the Royal Anthropological Institute in 1936 to report on the Swanscombe Skull and its site and by the choice of you as the officer responsible for the care of the collections and exhibits of fossil man and artefacts in the Natural History Museum, South Kensington.
>
> In collaboration with the chemists of the Government Laboratory, you applied the fixation of fluorine in bones and teeth to the dating of the Swanscombe Skull, to the Galley Hill Skeleton—thus ending more than sixty years of controversy—and to the Piltdown Skull.
>
> In the no less controversial realm of old river deposits you have used artefacts as zone fossils.
>
> Your handbook—'Man the Tool-Maker'—and your exhibits to illustrate the evolution of man show that you are not content to cater for the specialists only but wish to spread the light of knowledge to the ordinary student of geology and to the 'man in the street'.
>
> I have, therefore, great pleasure in handing to you the Henry Stopes Memorial Medal with the wish that it will stimulate you to further researches in your chosen field and I am sure all look forward to the delivery of the Henry Stopes Memorial Lecture in the near future.

Dr. Oakley said in reply:

> Mr. President: I thank you, Sir, for your generous remarks. I feel highly honoured that the Council should consider my work in prehistory worthy

of recognition in this way. Such contributions to the subject as I have been able to make were the result of entering the no-man's land between geology and archaeology mainly from the side of geology. I think my bent in this direction in boyhood was fixed by my father's gift to me of a copy of Sollas's 'Ancient Hunters'. I would not go so far as to claim that my dichotomy between fossil sponges and fossil man was due to following the example of Professor Sollas; but at least my approach to the Palaeolithic —partly geological, partly ethnological—owes much to the inspiration of his book.

That to some extent I have been able to follow this bent is due in the first place to the friendly guidance of my distinguished teacher, Professor W. B. R. King; and in the second place to my good fortune in having such a tolerant and sympathetic chief as Mr. W. N. Edwards. I feel much indebted to the many colleagues at the Natural History Museum and friends in this Association who have in one way or another helped and encouraged me in the development of the prehistoric side of geology—particularly the late Miss Dorothea Bate, Dr. W. J. Arkell, Professor Le Gros Clark, Mr. Hinton, the late Mr. Kennard, Mr. Lacaille, Mr. Marston, Mrs. Treacher, Mr. Hazzledine Warren, Professor Zeuner and many others. Nor do I forget, Sir, how much I owe to the stimulus of working for a time on the Geological Survey, and thereby coming into contact with you and your colleagues. Especially would I like to mention Mr. Bromehead, who, in the course of my work on rock-phosphates during the war, led me to take an interest in the geological aspects of fluorosis, which had an unexpected outcome; and Mr. Henry Dewey, who introduced me to the Swanscombe gravels.

It is appropriate to remember that the palaeontological riches of the Swanscombe gravels were first made known to the world by Henry Stopes at a meeting of the Anthropological Institute just over half a century ago. As further acknowledgment of our debt to that pioneer, I propose to take as the subject of this year's lecture in his memory: Swanscombe Man, his nature, culture, environment and dating.

Again I thank you, Mr. President, and, through you, the Council, for encouraging me to fresh efforts in the pursuit of knowledge of Prehistoric Man and his Geological Environment.

The Foulerton Award was presented to Mr. E. C. Martin in recognition f his great work for the Association. The President said:

Mr. Martin: Amidst a busy but non-geological professional life you have found time for geological research, to help others in that work, and to serve the Geologists' Association no less than thirteen years as Treasurer.

You therefore exemplify all that is best in our Association which, as is well known, carries a very large proportion of amateurs in its membership.

To me, figures and accounts simply represent hard and unpleasant work, but they obviously have no such depressing effect on you, for you are always cheerful.

Your geological work, begun many years ago in the west of England, reached a very high standard indeed along the south coast and I hope you will continue your field work now that you have more leisure. That your interest will continue in the Geologists' Association I am well assured, and it gives me much pleasure to hand to you the Foulerton Award as some outward sign of our appreciation of your services to geology and to the Geologists' Association.

The President then delivered his address entitled 'The Geological Survey of Coalfields: a report on progress'.

It was moved by Professor David Williams, seconded by Mr. G. W. Green, and duly carried 'That the best thanks of the Association be accorded the President for his Address'.

Ordinary Meeting, 7 *March* 1952.—Dr. G. W. Himus, F.G.S., President, in the chair.

Mohamed Kamal Akaad, Godfrey Hyde Ruthven Burrill, Gerald Hartley Gibbens, M.B., B.S., M.R.C.S., L.R.C.P., Miss Hazel Monica Green, Colin Robson Reynolds, Frank Stenhouse Ross and Kenneth George Stratford were elected Members of the Association.

Ordinary Meeting, 4 *April* 1952.—Dr. G. W. Himus, F.G.S., President, in the chair.

Stuart John McNichol, Mrs. May Catherine Mueller, Paul Rhodes, David Streeter, Reginald George Thurrell and Walter Deering Wells were elected Members of the Association.

The following lecture was delivered: 'Reptiles of the Mind', by W. E. Swinton, B.Sc., Ph.D., F.G.S.

The following papers were 'taken as read': (1) 'Structure and origin of the Malvern Hills', by F. Raw, D.Sc., F.G.S., and (2) 'Some Jurassic Brachiopoda from the Lincolnshire Limestone and Upper Estuarine Series of Rutland and Lincolnshire', by Miss Helen M. Muir-Wood, D.Sc., F.G.S.

Ordinary Meeting, 2 *May* 1952.—Dr. G. W. Himus, F.G.S., President, in the chair.

Charles Alex Urton Craven, Cecil R. Pinsent, F.R.I.B.A., Miss Geraldine Thorley, B.A. and Trevor Charles Welch were elected Members of the Association.

The following paper was read: 'Cliffs in Cardigan Bay and the extent of Post-Glacial Marine Erosion', by Professor Alan Wood, D.Sc., Ph.D., F.G.S.

Ordinary Meeting, 6 *June* 1952.—Dr. G. W. Himus, F.G.S., President, in the chair.

Alan McGugan, Alexander Gregory Stavridi and Elizabeth Waters were elected Members of the Association.

The following lecture was delivered: 'The Karstlands of Western Jugoslavia', by Miss Marjorie M. Sweeting, M.A., Ph.D.

Ordinary Meeting, 4 *July* 1952.—Dr. G. W. Himus, F.G.S., President, in the chair.

Sydney Leonard Brown, John Vivian Challis, Richard Charles John Edwards, Ronald William Elliot, Anthony Kenneth Hester, Robert Bruce King, Miss Rosemary Jean Lane, James Neville Donovan Lindner, John Raymond Lishman, Leslie Rowsell Moore, D.Sc., Ph.D., F.G.S., Alexander Roy MacGregor, Yousef Paran, Anthony William Spillett, Robert Wallace, Jnr. and Christopher Martin Wilson were elected Members of the Association.

The Third Henry Stopes Memorial Lecture, entitled 'Swanscombe Man', was delivered by Kenneth P. Oakley, Ph.D., F.G.S., F.R.A.I.

Ordinary Meeting, 8 *November* 1952.—Dr. G. W. Himus, F.G.S., President, in the chair.

Eileen Elizabeth Chagrin, Robert Frederick Simon Ellis, George Durell Freeman, John Inch, Charles Ian Milward O'Brien, Kenneth Edward Robinson, B.Sc., Vernon Roy Slaney, Sheila Margaret Tudor, William Waldron and B. O. Wymer were elected Members of the Association.

The Reunion which followed was held at Bedford College and was attended by about 300 members and friends. [For list of exhibits see below.]

Ordinary Meeting, 5 *December* 1952.—Dr. G. W. Himus, F.G.S., President, in the chair.

Sr. Teresa Alphonsa, P.C.J., James MacGregor Allan, B.Sc., Miss Eileen Winifred Andrews, Richmond Henry Arrand, Anthony John Barber, Miss Anne P. Bowater, Ernest Clifford Gale Bristowe, John Watson Cowie, Frederick George Damment, Joseph Gaddo, Miss Giuliana Rosemary Gotelee, Michael John Redwood Hammett, John Frederick Harrop, Harry Cyril Knapp Henderson, M.A., B.Sc., Ph.D., Kathleen Margery ordan, Alan Clive Nodes Lello, Miss Roslyn Esther Levy, Malcolm Donald McQueen, William Graham Henderson Maxwell, Kenneth Robert Mitchell, B.Eng., William Edmund Palmer, Gordon Prior, James Stephen Shackleton, Peter Howard Shelford, B.Sc., F.G.S., Miss Barbara Louise Short, Miss Nancy Tuff, Robert Derwent Walton, Charles Peter Watkins, Richard Bingley Whaler, Disney Alexander Wray, Ph.D., M.Sc., F.G.S. nd William Cecil Wright were elected Members of the Association.

The following lecture was delivered: 'Notes on the geology of the Blue Nile Valley near Roseires (Sudan)', by Francis Jones, M.Sc., Ph.D., F.G.S.

LIST OF EXHIBITS

Ager, D. V.

Exhibit illustrating the distribution of Domerian Brachiopoda in Britain.

Bairstow, L.
Ink-sac of fossil belemnoid revealed by radiography.

Bottley, E. P.
(*a*) Some Iberian type-rocks and minerals.
(*b*) British minerals.
(*c*) Fine crystals.
(*d*) New models and apparatus.

Carreck, J. M. and A. G. Davis
Stratigraphy and palaeontology of some Holocene alluvial deposits near Chertsey, Surrey.

Cox, L. R.
Scenes from the Algerian Sahara.

Dollar, A. J.
The early seismoscopes at Drumearn Comrie, Perthshire.

Edmonds, J.
Geological photographs of Morocco.

Eyles, V. A.
Bauxites from the Interbasaltic Horizon, NE. Ireland.

Hallimond, A. F.
Ore-microscope with polished sections.

Hayward, J. F.
(*a*) London Clay fossils from a London building site.
(*b*) An unusual edition of a geological classic.

Hughes, N. F.
Wealden plants.

Jones, F.
Specimens from the Blue Nile Rapids, Roseires, Sudan.

Joysey, K. A.
Chemical preparations of invertebrate fossils.

Owen, Ellis F.
A home-made simplified serial grinding apparatus and drawing apparatus.

Stinton, F. C.
Rarer fossils of the Barton Beds.

Thomas, H. Dighton and L. J. Pitt
A rare Polyzoon from the Lower Greensand of Faringdon.

Venables, E. M.
Auversian fossils from Bracklesham Bay.

Venables, E. M. and H. E. Taylor

New beetles and other fossils collected in 1952 from the London Clay of Bognor Regis.

Vogt, Miss M. C.

Petrological variations and rock structures from Ballachulish and Glen Coe.

Whitten, D. G. A. and E. T. Raine (Kingston Technical College)

Minerals and rocks collected on the Second Scottish Field Expedition.

Wright, C. W.

(*a*) Ammonite faunas and correlation of Cenomanian and Turonian in SW. England.

(*b*) Some American Cretaceous ammonites (Albian to Campanian).

Wrigley, A.

Tertiary Volutidae.

FIELD MEETINGS

The following field meetings and demonstrations took place:

19 *January*.—By kind permission of Prof. J. A. S. Ritson, a demonstration was held at the Royal School of Mines, Imperial College of Technology.

23 *February*.—A demonstration was held at the new Geology Department, Queen Mary College.

10–14 *April*.—The Easter Field Meeting was held in the Oxford district, where W. S. McKerrow and D. W. F. Baden-Powell demonstrated the geology of the Jurassic rocks and superficial deposits of Oxfordshire.

27 *April*.—The Lower Greensand area east of Maidstone was visited nder the leadership of B. C. Worssam.

18 *May*.—A. G. Davis, G. F. Elliott and H. E. P. Spencer directed an xcursion to the Stour Valley, where the London Clay and Pleistocene brickearth and gravels were studied.

25 *May*.—W. E. Swinton and W. H. Rivett led a party through the Mantell Country of the Weald.

30 *May*–2 *June*.—The Whitsun Field Meeting was held in Derbyshire, where the various facies of the Carboniferous Limestone were demontrated by J. Shirley.

21 *June*.—The cliffs sections from Hastings East Cliff to Ecclesbourne Glen, Fairlight Glen and Cliff End were studied under the leadership f A. F. Hughes.

6 *July*.—J. F. Hayward directed an excursion to Nazeing, Essex, and Broxbourne, Herts.

26 *July*.—The Cretaceous, Pleistocene and Holocene deposits of Barrington, Cambridgeshire, were studied under the leadership of B. W. Sparks.

16–30 *August*.—The Summer Field Meeting was held in South Shropshire under the directorship of Professor W. F. Whittard, who was assisted by H. W. Ball, F. G. H. Blyth, D. L. Dineley, J. H. James, R. W. Pocock, J. Shirley, A. J. Standring and C. J. Stubblefield.

27 *September*.—B. C. Worssam led an excursion to Leeds and Lenham, Kent.

11 *October*.—The Caterham and Godstone district was visited under the leadership of R. Bradshaw.

20 *November*.—Sixty members availed themselves of the opportunity of visiting the new Geological Department at Birkbeck College, where exhibits and demonstrations illustrating current researches were organised by A. T. J. Dollar.

NORTH-EAST LANCASHIRE GROUP

The following meetings and field meetings were held:

25 *January*.—Lecture: 'The geology of the Isle of Wight, Part I', by D. H. Learoyd, B.Sc., F.G.S.

29 *February*.—Lecture: 'Some geological and antiquarian features of the Ribble Valley', by F. C. Bond.

28 *March*.—Lecture: 'The glacial geology of Mid-Lancashire', by J. Ranson, A.M.I.M.E., F.G.S.

24 *May*.—Field Meeting: 'The Walsden Gorge', led by D. H. Learoyd, B.Sc., F.G.S.

28 *June*.—Field Meeting: 'Glacial overflow channels at Grey Stone Hill, Turton Heights and Hawkshaw', led by J. Ranson, A.M.I.M.E. F.G.S.

23 *August*.—Field Meeting: 'The Cliviger Gorge', led by I. A. Williamson

27 *September*.—Field Meeting: 'Lead mining near White Coppice' led by G. F. Urry.

31 *October*.—Annual General Meeting: Symposium of résumés on the Field Meetings.

28 *November*.—Lecture: 'The geology of the Isle of Wight, Part II' by D. H. Learoyd, B.Sc., F.G.S.

12 *December*.—Lecture: 'Intraformational contorted shale', by I. A. Williamson.

MIDLAND GROUP

The following meetings were held:

26 *January.*—'The Birmingham University Expedition to Spitsbergen', by P. A. Garrett, B.Sc., F.G.S.

8 *March.*—'Some aspects of the geology of the Stockholm Region', by H. Sanders.

18 *October.*—'Some problems of water supply in desert regions', by Professor F. W. Shotton, M.B.E., M.A., Sc.D., F.G.S.

15 *November.*—'Geological photographs and geological maps', by G. W. Himus, Ph.D., F.G.S.

13 *December.*—Exhibition of coloured and other photographs and Christmas party.

The following Field Meetings were held (average attendance forty-five):

2–4 *May.*—Dovedale, directed by D. Parkinson, D.Sc., Ph.D., F.G.S., F.Inst.P., F.I.R.I.

14 *June.*—Lichfield and Fauld Mine, Tutbury, directed by Professor F. W. Shotton and A. Bray, M.Sc.

12 *July* (Half-day).—Rowley, directed by E. D. Lacy, B.Sc., F.G.S.

27 *September* (half-day).—Turners Hill, directed by A. Ludford, M.Sc., F.G.S.

NORTH STAFFORDSHIRE GROUP

The following Meetings and Field Meetings were held:

10 *January.*—'Geology and the mining engineer', by E. Steele, Area Planning Engineer of the N.C.B.

14 *February.*—'Evolution and geological time', by S. H. Straw.

13 *March.*—Annual General Meeting. Chairman's Address: 'Rhythm in arth history'.

1 *May.*—'Uses of geology', by T. Eastwood, A.R.C.S., M.I.M.M., F.G.S.

14 *June.*—Field Meeting. Whole day to Wenlock Edge, led by F. W. Cope, D.Sc., F.G.S.

9 *October.*—Annual Conversazione in the Arts Centre Hall. Illustrated alk: 'Geological notes on Anglesey', by F. W. Cope, D.Sc., F.G.S.

18 *October.*—Field Meeting. Whole day to Miller's Dale, led by F. W. Cope, D.Sc., F.G.S.

13 *November*.—The Group were guests of Dr. F. W. Cope in the Geological Department of the University College of North Staffordshire.

11 *December*.—'Clay technology', by S. T. Davenport.

DONATIONS TO THE LIBRARY

AUSTRALIA, COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION.—Oceanographical Station List, vols. 1–4. Melbourne, 1951.

BIRMINGHAM UNIVERSITY, DEPT. OF GEOLOGY.—'The Lochaber Series south of Loch Levan, Argyllshire', by W. G. Hardie, 1952; 'On the development of *Diversograptus*', by I. Strachan, 1952; 'Allometric growth in *Dielasma hastata* from Treak Cliff, Derby', by D. Parkinson, 1952; 'Structure and origin of the Malvern Hills', by F. Raw, 1952; 'A new centre of stone axe dispersal on the Welsh Border', by F. W. Shotton, L. F. Chitty and W. A. Seaby, 1951.

BROWN, J. COGGIN.—'Contribution to the geology of the Province cf Yunnan in Western China. II. The Regional Relationships of the Ordovician Faunas', by the donor, 1950.

CAMBRIDGE, SGT. P., R.A.F.—Canada Arctic Expedition 1913–18, *Reports*, vol. 8, pt. B, 1925; 'The Jackson outcrops on the Red River', by T. L. Casey, 1902; 'On the probable age of the Alabama White Limestone', by T. L. Casey, 1901; 'On dynamic influences in evolution', by W. H. Dall, 1890; 'On some anomalies in geographic distribution of Pacific Coast Mollusca', by W. H. Dall, 1916; 'Tin through the ages', by F. J. North, 1941; 'On the denudation of the Culm Rocks from the area of South Devon', by A. Somervail, 1898; 'Discovery of letters by Lyell and Darwin', by H. P. Zuidema, 1947.

CONGO BELGE ET RUANDA-URUNDI, SERVICE GÉOLOGIQUE.—*Mémoire* No. 1. 'L'eruption du Volcan Gituro', by H. Tazieff, 1951.

DAVIS, A. G.—'*Howchinia bradyana* (Howchin) and its Distribution in the Lower Carboniferous of England', by the donor, 1951; 'The Brockenhurst Beds at Victoria Tilery, Brockenhurst, Hampshire', by the donor, 1952.

GEOLOGICAL SURVEY OF GREAT BRITAIN.—'The concealed coalfield of Yorkshire and Nottinghamshire', new ed., 1951; 'The Albite–Riebeckite Granites of Nigeria', 1952; 'The petrography of some of the Riebeckite Granites of Nigeria', 1952.

JAMAICA, GEOLOGICAL SURVEY.—*Bulletin* No. 1. 'The economic geology and mineral resources of Jamaica, 1951'; also reprints of three papers by members of the Survey.

LEACH, A. L.—'Éléments de préhistoire', by D. Peyrony, 1914; 'The scraper in prehistoric culture', by A. D. Lacaille, 1947.

LONDON NATURAL HISTORY SOCIETY.—Reports on temporary geological sections. 1950 & 1951; London Bird Report, No. 16, 1951.

MOURANT, A. E.—'Notes on the Holocene Deposits of Jersey', by the donor, 1952.

PITMAN (SIR ISAAC) AND SONS, LTD.—'Physical gemmology', by Sir James Walton, 1952.

TREACHER, MRS. LL.—Reports of the XVIIIth International Geological Congress, London, 1948.

WILLIAMSON, I. A.—'A glacial overflow channel near Burnley, NE. Lancashire', by the donor, 1952.

OBITUARY NOTICES, 1952

KATHERINE CUMMING BOSWELL died of heat-stroke on 18 September 1952, at Beni Abbes in the Sahara, during a field-excursion organised in connection with the XIXth International Geological Congress in Algiers. She was in her sixty-fourth year.

For eighteen years from 1926 she was a lecturer in the Geography Department at University College, Southampton, where she had previously been a student. She was a good all-round geographer with a wide background of knowledge of the Natural Sciences. She obtained an M.Sc. degree for her work on 'The Geography of the Port of Southampton', but her main interests always lay in geomorphology. In 1938 she became a member of the Geologists' Association, joined in its excursions with great interest and contributed 'A detailed profile of the River Test' to our PROCEEDINGS (1946, 57).

After resigning her post at Southampton she went, in 1945, to Highgate, Jamaica, as Co-Principal of the Friends' College. On returning to England in 1949 she resumed translation of 'Morphologische Analyse' by Walter Penck, completed it, and was pleased to have finished reading the proofs in the week before she left for Algiers.

As she was well acquainted with land-forms produced under thoroughly wet conditions, it was one of her dearest wishes to have first-hand experience of those associated with aridity. She had hoped in a pre-war visit to

South Africa to see the desert, but had not gone beyond the fringes of the Kalahari: she was therefore extremely happy immediately before her death to be reaching the depths of the Sahara.

The memory of her friendliness, generosity of mind and completely unassuming nature will be treasured by her former colleagues and students, members of the Society of Friends and others who knew her well.

D.E.W.

CYRIL EDWARD NOWILL BROMEHEAD died on 4 December 1952, leaving a widow and a son. He was born at York on 8 January 1885, and was educated at Marlborough and at Merton College, Oxford.

He joined the Geological Survey of Great Britain in 1909 and began work under Clement Reid, who set him to map an area along the lower Thames Valley which included most of London. This task was interrupted by the first world war (in which he fought as an infantryman until severely wounded), and by a short spell on post-war exploration for oil in Derbyshire, where a successful well—the first in Britain—was drilled at Hardstoft. Back to the London area in 1920, he spent two more years mapping under Henry Dewey, and with him devised the present nomenclature of the gravel-terraces in the Thames Valley. He made major contributions to the following maps and memoirs: London District (Edit. 2), North London (1-inch 256), Windsor, etc. (269), South London (270), Dartford (271). He became an authority on the geology and early history of London, and his work on the now-hidden tributaries of the Thames—Hole Bourne, West Bourne or Bayswater and others (see *Geogr. Journ.*, London, 1922, p. 125)—is especially notable.

In 1922 he returned to his native city as District Geologist charged with the resurvey of the Yorkshire Coalfield. With a handful of men he undertook this task with such zeal and ability that in fifteen years the bulk of the exposed coalfield, nearly 1000 square miles in extent, had been mapped in detail and reduced to stratigraphical order. Five memoirs—Huddersfield and Halifax (1-inch 77), Wakefield (78), Holmfirth and Glossop (86), Barnsley (87) and G. V. Wilson's Edition 2 of the 'Concealed Coalfield of Yorkshire and Nottinghamshire'—and the relevant maps and sections, were sent to press by the York Office during this period. In 1935 he took charge of Southern England where his staff were mapping the Chatham, Faversham and Sevenoaks areas of Kent. But again war supervened, and for much of the next ten years he was engaged on special tasks, in which members of the Geological Survey and Museum and of other bodies had cause to value his knowledge, experience and devotion to duty. He relinquished some of his responsibilities in 1945 and retired in 1949.

Bromehead was an active member of the Association. He was admitted in 1904, and in subsequent years led several excursions to localities in the Thames Valley and the London area. He served on the Council from 1938 to 1943 and as Vice-President from 1943 to 1946: he was President in 1946 to 1948, his addresses from the chair dealing with 'Practical Geology in Ancient Britain' (Part I, 'The Metals'; Part II, 'Non-Metals'. *Proc. Geol. Assoc.*, 1947, 1948).

His scientific and cultural interests covered a wide field. He belonged to the following societies: Geological (who awarded him the Lyell Fund in 1921), Royal Geographical, Hull Geological (he was President in 1933–4), Yorkshire Geological (Vice-President, 1935), York Philosophical; also the South-Eastern Union of Scientific Societies (President 1943–4) and the Yorkshire Naturalists' Union. He was a founder-member and council-member of the British Society for the History of Science. His published works ranged from pure and applied geology—e.g. 'On Diversions of the Bourne near Chertsey', *Sum. Prog. Geol. Surv.*, 1912; 'The Oil Horizons of England', *Geol. Mag.*, London, 1923; 'Geology of Reservoir Dam Sites', *2nd Congress on Large Dams*, Washington, 1936—to fluorosis (papers in *The Lancet*, 1941 and 1943) and, a subject he made peculiarly his own, the early history of geology and related arts and sciences—e.g. 'Evidence for Ancient Mining' and 'Early History of Water Supply', *Geogr. Journ.*, London, 1940 and 1942 respectively; 'Geology in Embryo', *Proc. Geol. Assoc.*, 1945; 'Aetites or the Eagle-stone', *Antiquity*, London, 1947; 'A Geological Museum of the Early Seventeenth Century', *Quart. Journ. Geol. Soc., Lond.*, 1947; 'Ships' Loadstones', *Min. Mag.*, London, 1948; and the presidential addresses mentioned above. These works reveal a remarkable depth of classical scholarship, combined with a firm geological and historical background, and give Bromehead a unique position among his contemporaries. They also show—what was occasionally found even in his official writings and still more in his lectures and contributions to debate—a whimsical touch reminiscent of his old Oxford professor, W. J. Sollas. And there is occasionally found in them something further, almost as if the fabulous were only just round the corner, which is surely seldom if ever attained by scientific writers.

Bromehead died while still at work in his favourite field of research. A wide circle of colleagues and friends will remember with affection his kindliness and culture, his interest in and, when invoked, staunch support of his subordinates, and his steadiness and initiative in times of stress.

W.E.

GEORGE ALEXANDER BURNETT died at his home near Ponteland, Northumberland, on 26 February 1952, at the age of sixty-two. A native of Dundee, he studied geology at the University College there, and afterwards

Longden took a great interest in the geology of the Nottinghamshire and Derbyshire coalfield and, during the years 1915–23, supervised the drilling of deep boreholes on behalf of the 'Stanton' Company in the Ollerton and Bilsthorpe areas. The information thus gained led to the sinking of shafts near these two places. His studies on the borings and shafts enabled him to publish important contributions to our knowledge of the structure of the north-east Nottinghamshire coalfield.

Longden became President of the Midland Institute of Engineers. He also served on the Council and as Vice-President of The Institution of Mining Engineers. In addition to his mining and geological interests, he did much work for the St. John Ambulance and devoted much time to the physical and spiritual well-being of the work-people of those areas.

H.H.S.

FREDERICK WILLIAM HUGH MIGEOD died at his home in Worthing on 8 July 1952. For the last year or so he had been a sick man and the quietness and inactivity that this imposed was in marked contrast to most of his life in which he was restless and inquiring and full of vitality.

He was born on 9 August 1872, at Chislehurst, but was educated at Folkestone, and, as soon as he was seventeen, he entered the pay department of the Royal Navy. His love of the Navy was lasting but the pay department appears to have been less attractive, for after nine years of it he entered the Colonial Civil Service and proceeded to West Africa.

In his new sphere his official duties were far from filling his life. He made serious studies in the native languages which resulted in five books; he undertook several hazardous transcontinental journeys and recorded his observations in four volumes. Back in England in 1925 he was attracted by the possibilities of the British Museum's East African Expedition then collecting dinosaur remains in Tanganyika. The leader, W. E. Cutler, had just died and Migeod at once volunteered for his place. He was accepted and for nearly four years struggled with a task that was not so congenial or so easy as he had expected. None the less he was still observing and the innumerable gleanings of a life-time's wanderings were neatly stored in his mind. They had to be considered and produced. Despite his Tanganyika commitments, Migeod was President of the Worthing Archaeological Society in 1927.

On his real retirement in 1929 he threw his energies into local affairs and into the study of evolution. He wrote books on 'Earliest Man' and 'Aspects of Evolution' and a 'Survey of Worthing'. He was elected a Town Councillor and a County Councillor and was eventually an Alderman of town and county. He was again President of the Worthing Archaeological Society in 1938.

He was not a passive member of local or London societies and played his part in their organisation and meetings.

He was elected to the Association in 1936 and was a member of Council from 1946 to 1949. He had something of a reputation for being difficult to get on with but this must have been with those who only knew him slightly. He was a charming host and his nearest friends alone knew of his many acts of friendship and generosity to those in difficulties. He lost his wife early in their marriage and had no children. For most of his life he was, in the domestic sense, a lonely man, but the abundance of his interests and the delight he found in all educational work and the pursuits of amateur naturalists will long be remembered, and may serve as a stimulus to those who remember him.

W.E.S.

HERBERT RUSHTON SYKES died at his home in Church Stoke, Montgomeryshire, on 15 March 1952, at the age of eighty-two. He was educated at Rugby and Oxford. From 1895 to 1902 he worked in the family business of bleaching near Manchester. In 1902 he became a member of the Association and in 1903 joined his cousins, Sir Percy and Lady Sykes, on an expedition to Persia. In 1904, he wrote an article on that country and subsequently lectured at the Royal Geographical Society, of which he became a fellow in 1907. He shot twice for England and received a commission in the Montgomery Yeomanry T.A. He became a major in 1914. He became keen on forestry and was a member of the Arboricultural Association, and in the First World War he was in charge of an Army agricultural scheme at Bury St. Edmunds. In his younger days he was an athlete of distinction. In 1935 Major Sykes was made an honorary freeman of the Borough of Bishop's Castle in recognition of his numerous services to the town. During the last war he was actively engaged in diocesan, educational and County Council activities and was appointed treasurer of the Royal Salop Infirmary in 1943 at the age of seventy-three. He will long be remembered for his wide interests and many activities in the welfare of his district. He is survived by his widow and four sons.

GERALD RALPH WILLAN, born at Hanley Swan, Worcester, in 1880, was the son of a naval doctor. He was educated at Repton and at Pembroke College, Cambridge, where he obtained the degree of B.A. Whilst at Cambridge he began to take an interest in geology and botany, but decided to make a career in industry. He entered the employ of Crawshay Bros. Ltd., of Merthyr Tydfil, as an assistant Colliery Manager and engineer, and subsequently became Agent for a group of collieries at Merthyr owned at that time by Guest, Keen and Nettlefolds Ltd. He retired in

1924 owing to indifferent health, and went to live at Cowbridge in the Vale of Glamorgan, where he found opportunity for renewing his interest in geology and botany. For a few years before his death he lived in Sheffield.

Willan became an active member of the Biological and Geological Section of the Cardiff Naturalists' Society, contributed to the discussion of papers and organised field walks. He joined the Geologists' Association in 1931, and showed his great interest in it by a bequest of the sum of one hundred pounds.

F.J.N.

HENRY WOODS, who was a member of the Association for sixty years and whose name has been familiar to many generations of geological students, died at Meldreth, near Cambridge, on 4 April 1952, in his eighty-fourth year. The son of a farmer, he was born at Cottenham, and entered St. John's College, Cambridge, in 1887, later becoming a scholar of the college. As a youth he came under the influence of McKenny Hughes, the Woodwardian Professor at Cambridge, and, after taking his degree in the Natural Sciences Tripos, he was awarded the Harkness Scholarship and was engaged in curatorial duties in the Woodwardian Museum. In the course of his early work, he produced two catalogues for the use of research workers and students in the museum; he also developed the patient industry and meticulous care that were to determine and characterise his subsequent work. Meanwhile he was appointed, in 1892, as demonstrator, a post which was reconstituted in 1900 as the University lectureship in palaeozoology; and he held this office until his retirement in 1934. The first edition of his now famous little book on palaeontology appeared in 1893 as one of the Cambridge Natural Science Manuals. By this time he had settled down to a teaching career at Cambridge and lived in rooms above the gateway of St. John's College, which he occupied until his marriage, in 1910, with Miss Ethel Skeat (daughter of Professor W. W. Skeat, the well-known Anglo-Saxon scholar), also a member of the Association. She died in 1939.

Although his first original paper, published by the Geological Society in 1894, was concerned with the igneous rocks of the neighbourhood of Builth, Woods's work in the museum had led him in the direction of systematic palaeontology, and his output of publications in this field is impressive. His first contribution to this subject, an account of the Mollusca of the Chalk Rock, drew attention to the presence of the attractive suite of fossils that characterises the *reussianum* Subzone in the South-east of England; and in the course of this investigation he made a study of comparable material in some of the continental museums. His attention was now engaged more particularly on the fossils of the Cretaceous formations, and, since there was obvious need for revision-work, he undertook to prepare a monograph of the Cretaceous Lamellibranchia. This work, which has been of much value to workers abroad as well as in this country, was published by the Palaeontographical Society, and occupied him from 1899 to 1913. The *Inoceramus* group in particular presented difficulties because of considerable variation and paucity of ornamentation. Very few of the types had been recognised and there was a lack of precise details as to horizon and locality of the historic specimens. The results of his work, however, have proved of good use in stratigraphy, for he was able to recognise phylogenetic series and to correlate modifications of the shell with geological horizons. These results were set out in a separate paper on the evolution of the genus in the Cretaceous Period, published by the Geological Society in 1912. Although he found the monograph an exacting task, and was frankly glad to see its completion, he began not ong afterwards a similar work on the Fossil Macrurous Crustacea of England, which was completed in seven annual parts (1925–31) and published by the Palaeontographical Society. Meanwhile, fresh material from abroad was being sent to him for determination and description and formed the subject of memoirs on Cretaceous fossils from South Africa, Northern Nigeria and New Zealand, and an account of some Tertiary fossils from Peru. In addition to this descriptive work he was the author of he chapters on trilobites and eurypterids in 'The Cambridge Natural History'.

At the end of his teaching career Woods was gratified with the knowledge hat many whom he met as pupils remained as friends. The value of his work met with due recognition: he was elected to the Royal Society in 1916, and was an honorary member of the Yorkshire Philosophical Society and of the Royal Society of New Zealand. From the Geological Society he received the Lyell Medal in 1918 and the Wollaston Medal in 1940. When he received the Lyell Medal he had the satisfaction of hearing his work described as 'faithfully pursued for no private end'—a high tribute, with which all who knew him would agree. C.P.C.

COASTAL EVOLUTION IN SANDWICH BAY

By A. H. W. Robinson, M.Sc. and R. L. Cloet, B.A.

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SUMMARY.—The origin of the dual feature of the inner Stonar shingle-bank and the outer Sandwich Bay spit can best be understood if the former is considered as a bay-bar formed by the on-shore migration of an off-shore bank. This theory of origin is supported by the movement of the present-day Brake, an elongated sand and shingle-bank lying 1½ miles off-shore in Sandwich Bay, as demonstrated by comparing hydrographic surveys of different dates. The outer ridge of shingle and sand forming the present coastline has grown as a normal spit from south to north.

1. INTRODUCTION

LYING across the eastern entrance to the former Wantsum Channel, which at one time separated the 'Isle' of Thanet from the mainland, is the natural constriction comprising of the inner Stonar shingle-bank bordered on the east by the Sandwich Bay spit (Fig.1). The Stonar Bank, extending from near Ebbsfleet in the north to the site of the former town of Stonar in the south, is largely composed of rounded-flint shingle and forms a natural causeway rising above the marshes on either side. The outer spit, forming the present coastline of Sandwich Bay from Deal northwards to Shell Ness at the mouth of the River Stour, overlaps Stonar Bank completely; it is composite in form, the shingle in the south gradually giving way northwards to sand and shell. The origin of this double feature raises a problem which has long interested coastal physiographers.

2. PREVIOUS WORK

Earlier writers have considered both features as being normal spits, the inner and earlier formed Stonar spit growing southward from Thanet and the outer and still-developing Sandwich Bay spit lengthening northwards from Deal. Various explanations have been advanced to account for the opposed directions of growth. H. Osborne White (1928, p. 74) postulated 'eddy drift' as the causative factor in the growth of Stonar.

Presumably the tidal streams moving from south to north along this coast would meet the projecting Isle of Thanet and, become deflected to the west and south, gradually extending the spit in the latter direction. There is no indication at the present time of this eddy effect and even if such an origin were possible, the growth of the outer spit with the same forces operating would be difficult to explain.

More recently Hardman and Stebbing (1940, p. 63) have suggested an origin of the two spits based on a change of direction in the currents consequent upon the opening of the Straits of Dover. Before the connection between the North Sea basin and the English Channel was complete, tidal streams in this area would be closely linked with water-movements in the southern North Sea. This would involve an anti-clockwise movement from north to south along the English coast, through the Wantsum Channel and thence a retreat along the Flemish coast. Stonar Bank, according to Hardman and Stebbing, grew as a result of this tidal pattern. Currents, which entered the Wantsum Strait through its northern entrance, would carry vast quantities of sand which would be subsequently re-deposited across the eastern entrance. On this base flint shingle from Thanet accumulated to form the inner spit. With the formation of the Straits of Dover, tidal-stream direction would be reversed and, with a water-movement now from south to north, Stonar would cease to grow and the development of the outer spit could begin under the new conditions, gradually lengthening northwards as material was added to its distal end.

The present writers are in agreement with this view of Hardman and Stebbing on the growth of the outer spit, although favouring longshore drifting and not tidal-stream action as being responsible. They cannot accept the view, however, that Stonar Bank antedates the formation of the Straits of Dover. Apart from the fact that this statement, on which the whole argument is based, is purely hypothetical, such an age would mean that Stonar has since been subjected to several eustatic changes of sea level of considerable magnitude, the effects of which cannot be estimated. A further difficulty in this theory of reversal of tidal-stream flow is that an analysis of present-day records for stations near the northern end of the adjacent Goodwin Sands shows that, even with the Straits of Dover open, there is still a net residual current running from north to south, i.e. from the North Sea into the English Channel.

Neither Osborne White nor Hardman and Stebbing satisfactorily explain the derivation of the hammered flints which form the bulk of the deposit. The most obvious source would be the Chalk of Thanet, but cliff-exposures at the present time show that it is relatively free from flint bands; this is reflected in the foreshore deposit which is formed of sand rather than of shingle. It is possible that some of the material may represent flint derived from the basal beds of the eroded Thanet Sands.

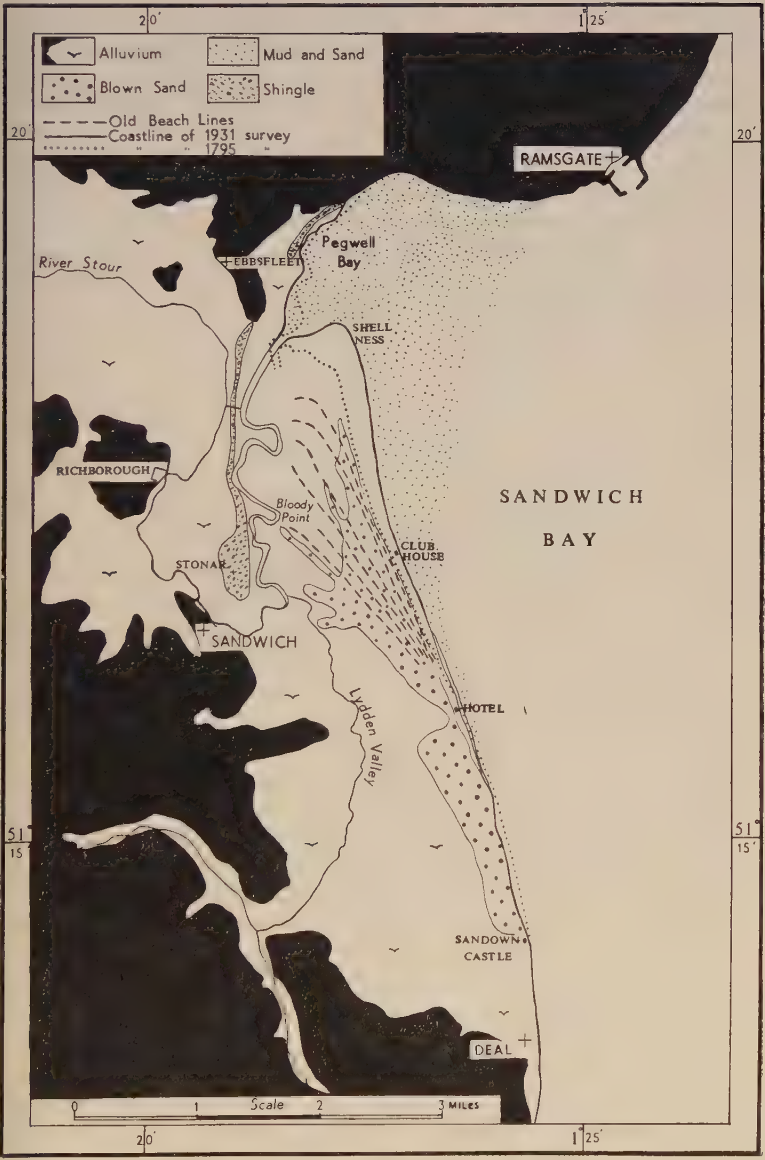


Fig. 1. The eastern entrance to the Wantsum Channel

As Professor J. A. Steers has remarked: 'It does not seem, therefore, that the southerly growth of Stonar has yet been properly explained' (Steers, 1946, p. 336). He then continues: 'There is further possibility of the spits having originated as a bay bar under present conditions, except for the recent growth of the northward pointing spit'. This view would seem, in the opinion of the present authors, to offer the most likely mode of origin for Stonar Bank. There is a considerable amount of evidence for the contention that the bay-bar arose as a result of the on-shore migration of a former off-shore shingle-bank, a theory of origin which will be discussed in detail later. The outer bank can then be considered as a normal spit which has grown from the south to completely overlap and enclose the former bay-bar.

3. NATURE OF THE EVIDENCE

Stonar shingle bank has been extensively quarried and dredged for ballast and, therefore, no information is available at the present time on the disposition of the shingle-fulls prior to disturbance. The many borings, put down by Messrs. Dorman & Long before the working began, do, however, give an indication of the initial form and extent of the bank, although data for adjacent bore-holes is often to reconcile when drawing sections (Fig. 2). In the north, near Ebbsfleet, where its base probably rests on re-sorted Thanet Beds, it is of no great depth. It is also very narrow at this point, not extending beyond the limits of the Ramsgate–Sandwich road which utilises it as a natural embankment. Traced southward, the breadth and thickness of the shingle increases until, near the southern extremity, the bank is 1750 ft. across and extends to a depth of a little over 40 ft. below Ordnance Datum (Liverpool) (Fig. 2, section 6). The surface height of the shingle also increases, reaching 16 ft. O.D. near the site of the ancient town of Stonar, a factor which influenced the initial siting of this 'dry point' settlement. At this point the shingle rests directly on the Chalk, the intermediate Thanet Sand having been completely removed.

The shingle is almost entirely composed of rounded flints which vary in size from 1 in. to 1 ft. in diameter. The larger shingle tends to lie on the seaward side of the bank. Mixed with the pebbles is a fine sand possessing all the characteristics of a modern beach-deposit, being thickest on the landward side where it often forms the dominant deposit. Banked against both shingle and sand on either side are extensive spreads of river alluvium. The southern limit of the shingle lies a little to the south of the old settlement of Stonar; borings for ballast between here and the quay at Sandwich have proved only small isolated thicknesses of gravel with a large admixture of silt. These minor lenses may represent shingle of the bank proper which has been re-sorted by the River Stour since its initial deposition. Modification of the initial form of the bank, especially by a river in spate, is a distinct possibility but it is doubtful whether erosion in itself accounts for the narrow neck of the feature in the north near Ebbsfleet.

Turning now to the outer spit, its form and growth-stages can be readily analysed from map-evidence and air-photographs. Comparison of the earliest accurate survey of the spit (Mudge's survey of about 1795) with the most recent Ordnance Survey map (based on a survey carried out in 1931) gives an indication of the rate of northward growth in the intervening period. Earlier stages are apparent from the evidence of air-photographs and these have been inserted in Fig. 1. The dating of these earlier shorelines presents a problem, although historical evidence, used in conjunction with the photographs, yields a partial solution.

Lying off-shore in Sandwich Bay at a distance of 1½ miles from the present coastline is the Brake Bank, a shoal over four miles in length with a width which varies from 1000 to 4000 ft. (Fig. 3 *a*). In transverse section, the bank is asymmetrical in outline, with a relatively steep infacing slope and a much more gently inclined, seaward 'dip'-slope. The gradient of the latter is of the order of 1: 500 compared with 1: 40 for the slope abutting onto the Ramsgate Channel which separates the Brake from the present coastline (Fig. 4). In form, therefore, the Brake has the characteristic features of an off-shore bank and is not dissimilar in form from the now inland Stonar Bank. The parallel can indeed be carried even further for the Brake is formed partly of shingle with an admixture of sand and shell-fragments.

The movement of the Brake Bank can be measured by comparing hydrographic surveys (on a scale of two inches to a nautical mile) of the area, undertaken at various times in the past 100 years. To facilitate comparison, a map showing changes in depth has been prepared by superimposing the survey of 1947 on that of 1896 and plotting the intersections of the two sets of fathom-lines as isolated 'spot-depths' of positive or negative change. These were then joined by isopleths to form areas of deepening and shoaling (Fig. 3 *b*).

4. THE EVOLUTION OF STONAR BANK

We are now in a position to discuss the origin of the inner shingle-bank. Borings, taken in the eastern arm of the Wantsum Channel at various times, show that, at one stage in its history, it existed as a scoured channel at a depth of about 40 ft. below the present mean sea level. The scour, mainly tidal, was sufficiently strong in places to remove the cover of Thanet Sands which formerly rested in the lap of the Wantsum Channel syncline.

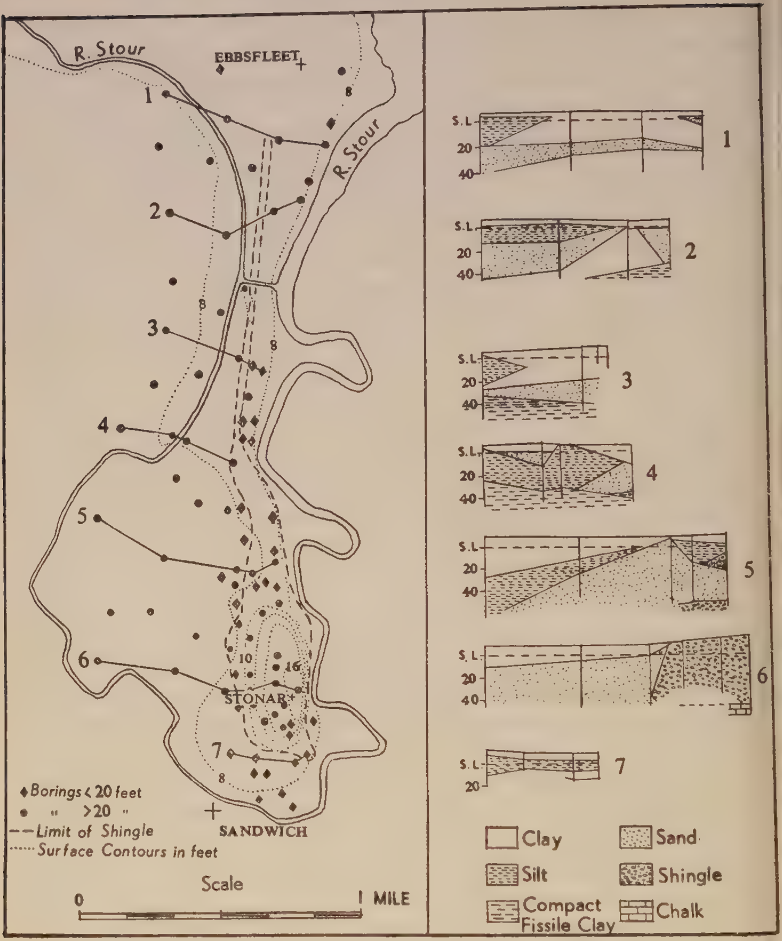


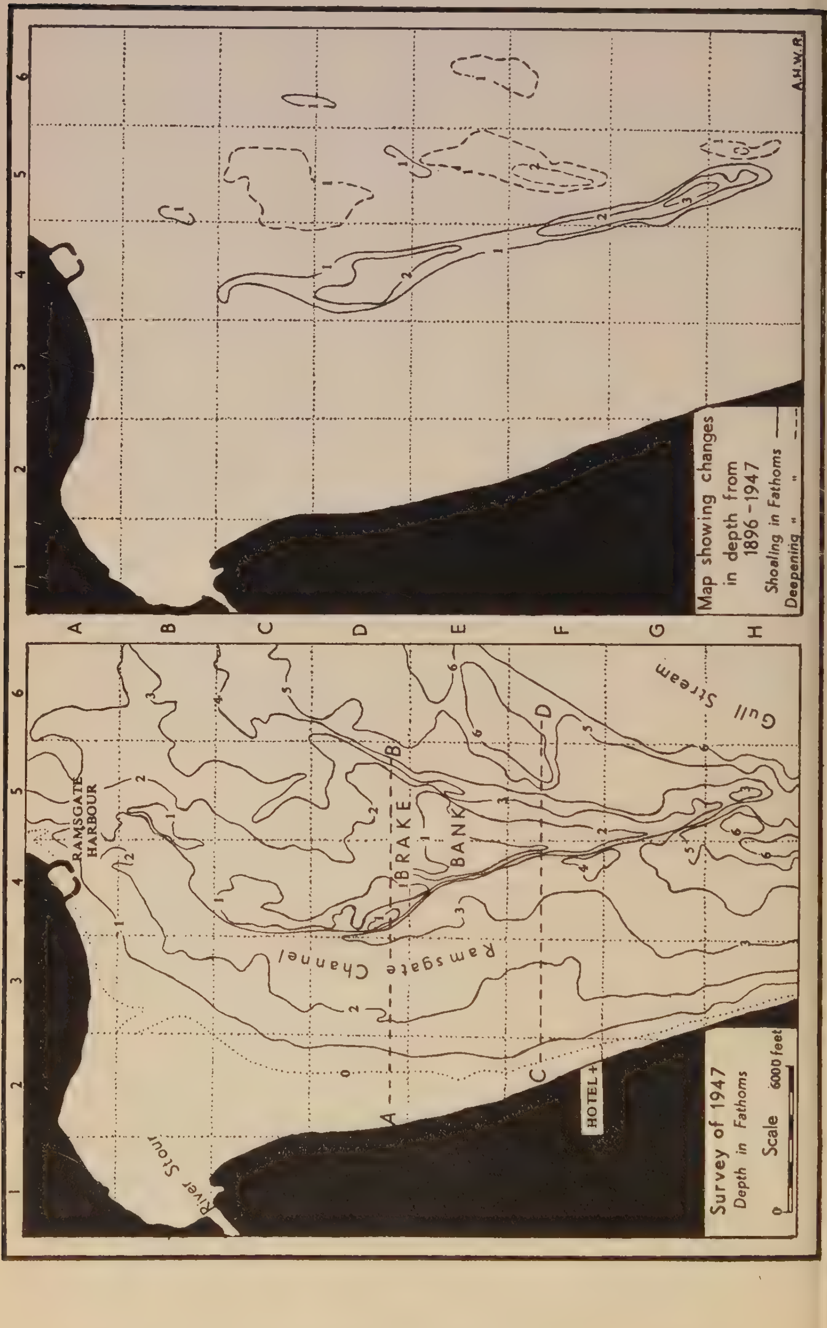
Fig. 2. The form of the Stonar shingle bank as deduced from boring data

The eastern end of the channel, with which we are concerned in the present discussion, was funnel-shaped in plan, extending for a distance of about six miles from the neighbourhood of Walmer in the south to the Chalk cliffs near Ramsgate in the north. Farther west the channel narrows to less than three miles in width between the 'hard' of Thanet Beds, on which the present town of Sandwich is situated, and a similar outcrop near Ebbsfleet (Fig. 1). The latter, which extended as a southerly prolongation from the southern side of Thanet, may represent, at least in part, material scoured from the centre of the channel and drifted from west to east to be re-deposited near the eastern entrance.

Off-shore the bottom-topography was probably as uneven as it is at present. The Pleistocene ice-sheet had left in its wake vast deposits of sand and shingle covering the floor of the North Sea, which had been shaped by wave- and current-action into a number of elongated north–south trending banks (Robinson, 1952, p. 76). One of these may have existed to the south of Ramsgate in the position of the present-day Brake. It is suggested that this hypothetical bank moved steadily west-south-west. One possible cause of this coastward movement is that it was subject to wave-attack generated by the dominant as opposed to the prevalent wind. Because of the shape of the North Sea, especially its southern basin—the Flemish Bight—the direction of maximum fetch for this coast lies in the north-east quadrant. The migration of the bank, however, would not be directly south-west because the off-shore bottom-topography has the effect of turning the wave-front so that the waves tend to arrive more directly on-shore, thus inducing a more westerly component into the movement. This is in accord with the views of W. V. Lewis (1938, p. 109), who has suggested that the effective waves for shoreline evolution approach from a direction intermediate between the direction of maximum fetch and the perpendicular to the present shore. Under this influence, the on-shore movement would continue until the bank became grounded on the Thanet Sand prolongation in the constricted part of the Wantsum Channel. The shingle had to mould itself to the existing submarine form of the channel and, for this reason, it is thickest in the area of Stonar, the site of the former deep-water axis. Accumulation at the northern end would tend to be less because of the shelter afforded by the promontory of Thanet from the effective wave-building forces.

An alternative explanation of the on-shore movement would assume the simultaneous existence of a bank in a position similar to that of the present-day Goodwin Sands. An anti-clockwise rotary movement of these Sands would induce a corresponding landward movement of the proto-Stonar Bank if the channel between the two was to remain at a constant width. Once the proto-Stonar Bank reached shallow water, longshore drift, acting as it does on the present-day Sandwich Bay spit, would establish a tenuous join with Thanet.

Whichever explanation of the on-shore movement is followed, it is apparent that, in its later stages, the shingle-bank would simulate a bay-bar, although it is doubtful whether it extended across the full width of the Wantsum Channel. There was probably a gap between Stonar and Sandwich which was used by the River Stour at a later date when the sea channel finally disappeared. The silting up of the strait would begin as the Stonar Bank prevented a through tidal scour. No corresponding embank-


Map showing changes
in depth from
1896-1947
Shoaling in Fathoms
Deepening " "
A.H.W.R.
Survey of 1947
Depth in Fathoms
Scale
0
6000 feet
RAMSGATE HARBOUR
BRAKE
BANK
Ramsgate Channel
Gull Stream
River Stour
HOTEL +
A
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ment existed across the northern entrance, the closure here being entirely artificial and dating from the fifteenth century, when walls were built as part of a general scheme of inning.

A study of recent movement of the Brake Bank will show that on-shore movement, as envisaged above, can take place in this area. Hydrographic survey records covering the last fifty years indicate that, during this period, the shoal moved west-south-west a distance varying from 1000 ft. (Fig. 3 *b*, square G 5) to over 2000 ft. (square D 4). Material has been added to the inner face of the bank and removed from the eastern side in long elongated belts of shoaling and deepening as shown in the figure. Whether it is a simple transfer of shingle and sand from the outer to the inner side of the bank cannot be definitely proved but the indications are that this is by no means unlikely. Storm-waves approaching from the north-east, becoming deflected more to the westward as they meet the shelving bottom, would be fully capable of effecting such a movement thus causing the Brake Bank as a whole to move landward. Local evidence also illustrates the above conclusion, for, during storm periods with heavy seas running, the shingle of the bank can be heard to roll as the waves break over it. The indications are, then, that in the steady landward movement of the Brake Bank today, we have a process simulating one which has taken place in the past.

No precise age can be assigned to the formation of the bay bar of Stonar. Remains of coins, pottery, etc., found amongst the shingle indicate that it existed in Roman times when it must have severely narrowed the eastern entrance to the much-used Wantsum Channel. The shingle was also used to build the walls of the Roman fortress at Richborough, less than a mile to the westward. Hardman and Stebbing (1940), in consequence of their theory of origin, thought of it as pre-dating the formation of the Straits of Dover, but if their hypothesis of tidal drift from the north is unacceptable, it is unnecessary to stipulate such an early date for its formation. It is also unnecessary to assign a late glacial date for its initiation, as Steers (1946, p. 336) tentatively suggested, when, following Harmer, there would be a reversal in the direction of the prevalent wind. As has been demonstrated, on-shore drift can take place under present conditions. The present authors, in view of the state of preservation of the feature and other considerations, are inclined to assign a pre-Roman but not pre-Neolithic dating, though we fully admit that conclusive evidence is lacking.

5. THE GROWTH OF THE OUTER SPIT

There is a fair measure of agreement on the origin of the spit which forms the present coastline from Deal northwards to Shell Ness. Most authorities envisage a growth from the south as material was added by longshore drift to the distal end, which in consequence moved steadily northward. Evolution stages have been inserted in Fig. 1 from air-photograph analysis.

The spit is a composite feature, the outer edge being a true shingle-bank rising to 20 ft. O.D., stretching from Deal to the neighbourhood of the Guildford Hotel. On the inner margin are the marshes of the Lydden Valley, the monotony of which is occasionally broken by sand-dunes varying in height from 10 to 30 ft. Northwards from the hotel, the shingle is replaced by sand with an ever-increasing admixture of shell-fragments. The shingle is gradually extending farther north, being added to the earlier-formed bank of sand. There is a tendency for the head of the spit to become recurved, a feature not only of the present shoreline but also of the 'fossil' beach-lines preserved within the spit. Accompanying the northward extension, there has been a broadening as successive beach-lines have formed farther seaward (Fig. 1).

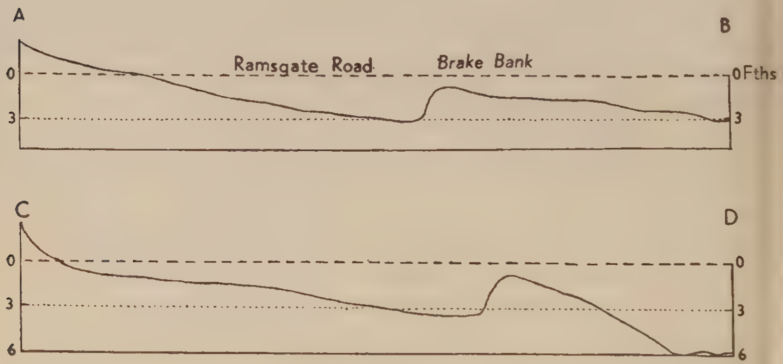

Fig. 4. Transverse sections across the Brake Bank (Vertical Elevation x 50). The positions of the section-lines are shown on Fig. 3 *a*

Although the present authors are in agreement with earlier writers on the question of the origin of the spit, we cannot accept the dating and some of the various estimates of the rate of growth which have been given. Hardman and Stebbing think of the feature as growing subsequent to the opening of the Straits of Dover when present-day tidal conditions were initiated. In their view it is of a much later date than the inner shingle-bank. That this is true of the northern part where it overlaps Stonar is unquestionable. It is possible, however, that the southern part of the spit in the neighbourhood of Deal was developing concurrently with the shoreward migration of the shingle-bank.

The northward rate of growth has been variously estimated. Redman (1854, p. 166) assumed that in the late sixteenth century, the head lay in the latitude of Sandown Castle, a view which, if correct, would mean a lengthening of the order of five miles in 350 years. There are many reasons for disputing such a rapid rate of growth of the spit. Remains, indicative of settlement in Roman times, have been found in the Tennant Sand Hills to the north of Sandown Castle (Smith, 1850, p. 53). Measurements based on the accurate topographic surveys on the 1-in. scale over the past 150 years, give a rate of growth of 1880 ft. in a 136-year period. Between 1876 and 1931, the dates of the earliest and most recent survey on the 6-in. scale, the extremity moved 1000 ft. northward. If these rates of growth are accepted as having remained relatively constant over the past 1000 years, the suggestion that Bloody Point was at the head of the spit at the time of the battle in A.D. 851 would seem valid.

6. CONCLUSION

It remains to consider how far the above concept of the origin of Stonar Bank and the part it has played in the evolution of the Sandwich Bay shoreline, has more general application. Near-shore banks similar to the Brake are prominent elements in the coastal waters around the British Isles. In the North Sea basin they probably nearly all represent glacial deposits re-sorted by wave- and current-action and thrown up into a number of banks lying broadly parallel to the coast. Unfortunately, in most cases, not enough hydrographic data of sufficient accuracy is available for studying their true movement but the indications are that many migrate shoreward. On the other side of the Straits of Dover, Briquet (1930, p. 265) mentions the evolution of the Banc à la Ligne in Wissant Bay, north of Cap Gris Nez, which in 1640 was entirely off-shore but by 1911 had almost merged with the present coastline.

Only in special circumstances such as along embayed coastlines will their shoreward migration result in the formation of a bay-bar feature. In general, along a straight coastline, they would tend to act solely as a constant source of supply for beach-material, becoming involved in normal shoreline processes such as longshore drifting. In some areas the movement landwards may only involve individual pebbles rather than whole ridges of shingle. Commander E. K. Calver, a hydrographic surveyor who possessed an intimate knowledge of the hydrography of the southern North Sea, expressed the process which the authors have in mind when, referring to the sea-bed between the Suffolk coastline and the off-shore shingle-ridges, he stated that 'if it had been possible to uncover the bottom of the sea, it would have presented the appearance of a sandy waste with single pebbles scattered over it, travellers, as it were, from the ridge to the shore' (Redman, 1863, p. 245).

This would help to explain the vast accumulation of material in some of the east coast spit-formations, particularly Orfordness with its succession of shingle-fulls. Lying five miles off-shore in this area, hydrographic surveys have disclosed an extensive bed of shingle, a feature which, elsewhere in the North Sea, has been interpreted as the remains of a glacial end-moraine (Pratje, 1951, p. 106). Under wave-action, particularly during storm periods, it is suggested that some of this shingle has moved landward and become involved in longshore drifting, supplementing the local material available for building the shingle-fulls.

ACKNOWLEDGMENTS

The authors wish to express their indebtedness to Messrs. Pearson and Dorman Long Ltd. for bore-hole information from which Fig. 2 was prepared, to the Hydrographer of the Navy for hydrographic survey data reproduced in Fig. 3 and to the Central Research Fund, University of London, for a grant to cover the cost of maps, etc. Thanks are also due to Dr. P. R. Crowe, to Dr. J. F. Kirkaldy, both of the University of London, and to Mr. W. V. Lewis, of the University of Cambridge, for valuable comments on the substance of the paper.

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DISCUSSION

Mr. R. L. Cloet, who has been making a more comprehensive study of the hydrography of the adjacent Goodwin Sands, added some remarks on the interplay of the movement of the present-day off-shore banks.

Lying to the east of the Brake Bank and extending NNE.–SSW. for a distance of about ten miles, are the Goodwin Sands (see Admiralty Chart No. 1828). In shape the latter resembles a pair of calipers with the features of the Fork and South Sand Head at their distal ends and Trinity Bay lying between them. An analysis of tidal-stream data shows that the residual current is toward the English Channel in the latitude of the Brake but in the opposite direction near the southern extremity of the Goodwins.

The apparent conflict between these two sets of residual currents may be explained as follows: the ebb-tidal stream, coming from the North Sea, flows against and around the Goodwins but has only an indirect effect on the circulation in Trinity Bay. The flow-stream directed towards the North Sea from the Straits of Dover has its full effect at the southern extremity of the Sands. Resulting from this we have a system of ebb- and flow-channels in and around the Sands. The flow-channel in Trinity Bay continually attempts to widen the Bay, whilst the ebb-channel of the Gull Stream (between the Brake Bank and the North Goodwins) also attempts to maintain itself and keep the volume-flow of water in it undiminished. Such being the case, the eastward movement of the Fork must cause the Brake Bank to curve into Sandwich Bay. That this is so can be seen from a study of the hydrographic surveys of the Brake since 1795, when the first accurate survey was undertaken. Since that date the bank has moved consistently shoreward, the movement being greatest along the central axis and less rapid at the southern extremity.

Additionally another movement may be observed. The flow-channel working inside the Goodwins appears to be severing a limb of the Fork from the main body of the Sands. This may be an attempt at throwing off a bar which would start travelling coastward in the same way as the Brake Bank and, possibly, in the same way as the earlier Stonar Bank.

ALDERMAN W. P. D. STEBBING, in some general remarks on this paper which offered a different explanation of the growth of the Stonar Shingle-ridge than that given by him and the late Mr. F. W. Hardman—'Stonar and the Wantsum Channel' (in *Arch. Cantiana*, 1940–2, 53–5)—looked on the evolution of the area as one still in need of further study by the authors. While there were three banks of rolled debris from the decay of Chalk cliffs there was, in the case of Stonar, in addition to flint of all sizes, tabular and green-coated flint from the base of the Eocene, rolled masses of silicified wood from the Thanet Beds and, as a puzzle, a small number of igneous and other erratics—drift from some glaciated source.

With a possible commercial development of the material from the South Brake some questions may be answered. He was delighted to have been able to join in the discussion.

PROFESSOR J. A. STEERS said that he was glad that the authors had taken up the study of this interesting piece of coast, with which he was not very familiar, but it had long seemed to him worthy of detailed investigation. Although he could not add to what the authors had said, he would like to ask some questions. Were there any ridges or recurves on the inner, Stonar, bank? If there were—he realised building and other operations may have destroyed them to some extent—they should help much in substantiating the nature of its origin. Why, too, was this Stonar Bank so much higher and more massive at its southern end? He did not think the lecturer [Mr. Robinson] had emphasised any differences between the nature and composition of the inner and outer banks. If there were any marked differences they might well throw light on the nature and origin of the two banks.

If he had understood the lecturer correctly, the authors suggested some kind of cyclical hypothesis for the two banks, and they related this possibility also to the known movement of the Brake Sand. Was there anything in the known history or evolution of the banks themselves which bore on this matter? It was with this point in mind that he had asked the earlier questions.

In conclusion, Professor Steers said that he was glad that the authors were also thinking in terms of the changes in and the effects of the Goodwin Sands. He hoped very much that they would continue their work, and congratulated them on what they had already done.

MR. E. J. LAKE said it would be of interest if the authors could say if they had any theory about the original source of the material in the Stonar shingle-bank and the Sandwich Bay spit. The shingle in the former, like that forming the beach between Reculver and Minnis Bay along the northern limit of the Wantsum marshes, was predominantly black, while that between the Guildford Hotel and Deal was ferruginous.

If, for the purposes of discussion, it may be taken that the age of a flint dates from the time when it first left its Chalk matrix, does this difference in colour show that the flints of the northern beach and the Stonar Bank are 'younger' than those of the Sandwich Bay spit and have the latter acquired their colour from long resting in beds of river-gravel?

Can the authors say if the shingle of the Brake is of flint and if so what is its dominant colour?

THE AUTHORS, in reply, after thanking members who had participated in the discussion, attempted to answer some of the questions put by the various speakers. With regard to Mr. Stebbing's point on the presence of igneous erratics in the Stonar Bank, these are known to occur in the bottom deposits in the southern North Sea and are presumably of glacial origin. Their occurrence, therefore, in the Stonar deposit would substantiate the mode of origin of the latter as suggested in the paper.

In answer to the questions of Professor Steers, the authors replied that: (1) any ridges which may have existed have long since disappeared. Since 1926 the shingle near the surface has been completely stripped during the working for ballast. The information which we have about the bank is derived solely from the borings put down before the exploitation began; (2) the bulbous southern end of Stonar Bank is difficult to explain. Because of the shelter afforded by the Isle of Thanet, material is less likely to have drifted in to the same extent in the northern part compared with the southern. The effect of the Isle of Thanet is also illustrated by the present disposition of the Thanet Sand deposit. Near Stonar the deposit has been entirely removed whilst near Ebbsfleet the sequence has remained intact; (3) both the inner and outer banks are composed of shingle and sand. The Stonar shingle is, however, much larger than that of the outer spit and in addition contains igneous erratics. No such erratics have been found in the outer spit. This suggests a different source for material of both banks; (4) the movement of the Goodwin Sands may be taken as illustrative of possible cyclical effects for under favourable conditions the western limb of the latter may be severed and begin to drift shoreward. Stonar and the Brake Banks may have been former limbs of the Goodwins and therefore represent two pulsations in a possible cycle.

On the evidence of the different types of shingle in the Stonar Bank and the Sandwich Bay spit, the authors are of the opinion that this may indicate no more than different sources of material. As we are probably dealing with re-sorted material, the age of the flint may bear little relationship to the age of these features.

No direct evidence of the character of the shingle of the Brake Bank is at present available, but with the possible commercial development of the deposit, as mentioned by Mr. Stebbing, this question will be answered.

SECTIONS IN THE CORALLIAN BEDS AT BECKLEY, OXFORDSHIRE

By J. H. Callomon, B.A.

[*Received* 14 *September* 1952]

SUMMARY.—The stratigraphy and palaeontology of quarry-sections in the Corallian Beds at Beckley, Oxon, a village four and a half miles north-east of Oxford, are discussed and the extensive ammonite fauna collected from these strata is listed.

INTRODUCTION

FOR the past six years, the writer has periodically visited and examined the Corallian quarries in the neighbourhood of Oxford. A number of these quarries have been actively developed since they were recorded by Arkell (1936 and 1943); some have subsequently been abandoned, and some are being obliterated by infilling with rubbish. Three quarries at Beckley, Oxfordshire, which were visited by members of the Association on Sunday, 12 August 1951, have yielded an interesting and extensive ammonite fauna and, as this also throws light on the age-relationship of the sandy beds to the overlying limestones, it is thought that the details should be placed on record.

WOODPERRY ROAD QUARRY, BECKLEY

This quarry lies on the south-west side of the road between Beckley and Woodperry, half a mile south-west by west of Beckley Church (National Grid Reference 42/569.109). This section has been briefly recorded by Arkell (1943, p. 190) and, with the two other quarries, details of which are given here, is marked on Arkell's map (*idem.*, pl. 7).

Osmington Oolite Series (Wheatley Limestones)

		ft.	in.
11.	Marly Rubble, with limestone lumps ... ... seen	3	0
10.	Limestone Band, hard, white, crystalline and unfossiliferous, weathering slabby (east side only, possibly disturbed)	1	3
9.	Marly Rubble, greenish, soft	3	6
8.	Pendle. Intensely hard, white limestone, weathering flaggy ...	1	3
7.	Rubbly Limestone, argillaceous, hard locally. *Perisphinctes* fragments, incl. *P.* (*Perisphinctes*) *parandieri* de Loriol	3	0
6.	Second Hard Band. Massive, crystalline limestone, weathering brown locally. *P.* (*Perisphinctes*) *chloroolithicus*, *Pseudomelania heddingtonensis* (Sow.)	1	3
5.	Marly Rubble, compact locally to limestone. *Perisphinctes* sp., *Nucleolites scutatus* Lamark	2	0
4.	Bottom Hard Band: Urchin Bed. Hard, grey crystalline limestone, locally gritstone, and locally merging into sand downwards. Profusion of sea-urchins, *Nucleolites scutatus*, Lamk. Spines of *Paracidaris*, also *Perisphinctes* sp. fragment, *Pseudomelania heddingtonensis* (Sow.), *Pleurotomaria reticulata* Sow.	2	0

ft. in.

3. Oyster Clay. Black, marly clay, crowded with oysters and *Serpulae*. *Pachyteuthis abbreviatus* (Miller), *Gryphaea dilatata* Sow. var. *controversa* Roemer, *Exogyra nana* (Sow.), *Chlamys* (*Radulopecten*) *fibrosa* (Sow.), *Serpula* spp. (large) 0 6

(ERODED SURFACE)

2. Shell Pebble Bed. Rubbly limestone, a mass of fossils; also round, bored and *Serpula*-encrusted pebbles of limestone and ammonite fragments derived from the Berkshire Oolites; occasional lydites and quartz. *Pleurotomaria reticulata* Sow., *Lima* (*Plagiostoma*) *mutabilis* Arkell, *Astarte ovata* Smith (profuse); *Pachyteuthis abbreviatus* Miller, and crushed fragments of *Perisphinctes* spp. derived from below. Ammonites:

Perisphinctes (*Perisphinctes*) *chloroolithicus* (Gümbel)
P. (*Dichotomosphinctes*) *buckmani* Arkell
antecedens Salfeld
rotoides Ronchadzé
ouatius (Buckman)
P. (*Arisphinctes*) *ingens* (Y. & B.)
cotovui Simionescu (500)[1]
helenae de Riaz
vorda Arkell
P. (*Kranaosphinctes*) *cymatophorus* (Buckman)
Cardioceras (*Scoticardioceras*) *excavatum* (Sow.)

1 0

(UNCONFORMITY)

Berkshire Oolite Series

ft. in.

1c. Sand, evenly-laid, ferruginous, wedged out in north by Bed 2 up to 2 0

1b. Sandy Limestone, gritty, yellow, passing into sand locally; is in contact with Bed 2 in the north end of the quarry and there becomes welded to it in an apparently single band. The ammonite fauna[2] includes:

Perisphinctes (*Perisphinctes*) *chloroolithicus* (Gümbel)
P. (*Dichotomosphinctes*) *antecedens* Salfeld
rotoides Ronchadzé
magnouatius Arkell
sp. undescribed aff.
ouatius (Buckman)
sp. undescribed aff.
maltonensis Arkell
P. (*Arisphinctes*) *maximus* (Y. & B.)
cotovui Simionescu
helenae de Riaz
vorda Arkell

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[1] The measurement in millimetres following each name refers to the maximum size of the complete shells.

[2] Careful distinction must be made between ammonites from Bed 1b and Bed 2 where the beds are welded together in the north end of the quarry.

ft. in.
P. (*Kranaosphinctes*) *cymatophorus* (Buckman)
Cardioceras (*Scoticardioceras*) *excavatum* (Sow.) 0 8

1a. Sand, evenly laid, brown, ferruginous with impersistent doggers and layers of gritstone; giant ammonites
Perisphinctes (*Arisphinctes*) *maximus* (Y. & B.) (500)[2]
ingens (Y. & B.) (500)
ingens-cotovui (400)
cotovui Simionescu (450) (400) (400)
cowleyensis Buckman (500)
pickeringius (Y. & B.) (570) (300)
helenae de Riaz (350)
P. (*Kranaosphinctes*) sp. undescribed aff.
decurrens (Buckman) (500)
sp. indet. (450)
bullingdonensis Arkell, (one body-chamber)
Cardioceras sp., a brood of nuclei in the body-chamber of one of the above
seen to 4 0

The section given above may be compared with the succession at Messrs. Benfield and Loxley's quarry as described by Arkell (1936, p. 171), situated on the east side of the road about half a mile south of Beckley church (National Grid Ref. 42/566.104). Bed 2 in the section detailed above is the equivalent of Beds 9 and 10 in Arkell's list, and the thickness is reduced to one foot from six feet. Bed 1 given above is probably Arkell's Beds 1 to 3. All the intermediate Beds 4 to 8, sixteen feet of sands and gritstone, in Arkell's section, are missing at the Woodperry Road quarry, and have presumably been wedged out in the unconformity below Bed 2 as given in the section above.

Since Arkell published his description in 1936, Messrs. Benfield and Loxley's Beckley quarry has been further enlarged and is now abandoned. On extending the workings northwards, somewhat higher levels still of Arkell's Bed 8, the top of the Beckley Sands, came in with the unconformity, and yielded further ammonites. These again are easily distinguishable in their preservation from those at the other two ammonite-bearing levels, that is Arkell's Beds 3 and 10. The ammonites are:

Perisphinctes (*Arisphinctes*) *cotovui* Sim., *P.* (*A.*) *pickeringius* (Y. & B.), *P.* (*Kranaosphinctes*) *trifidus* (Sow.), *P.* (*K.*) *decurrens* (Buckman), *Cardioceras* (*Scoticardioceras*) *excavatum* (Sow.), *C.* (*Maltoniceras*) cf. *highworthense* Arkell, *C.* (*Cawtoniceras*) *cawtonense* (Bl. & H.), *C.* (*Subvertebriceras*) *zenaidae* Ilovaisky, *C.* (*Vertebriceras*) *vertebrale* (Sow.), *C.* (*Sagitticeras*) sp., *Goliathiceras* cf. *gorgon* Arkell.

This bed has also yielded the following echinoids which are rare in the British Corallian:

Holectypus depressus Leske, *H. corallinus* d'Orbigny & Cotteau.

HORTON ROAD QUARRY, WOODPERRY

The third quarry in the Beckley area, which was marked on the map by Arkell (1943, pl. 7) but not described, is situated on the north-west side of the Headington to Horton-cum-Studley road, three-quarters of a mile south-west of Beckley church (National Grid Reference 42/571.104). The quarry has been enlarged considerably during the past decade, but it is now abandoned. The succession corresponds closely to that in the Woodperry Road quarry and the numbers given to the beds tally in both lists. It will, however, be seen from the details which follow that there is some variation in thickness in tracing the beds from the south-east to the north-east of this quarry.

Osmington Oolite Series (Wheatley Limestones)

	SE. end				NE. end			
	ft.	in.	ft.	in.	ft.	in.	ft.	in.
11. Rubble ... ... seen			2	0			2	0
10. Limestone, hard, white, weathering slabby			1	0			1	0
9. Marly Rubble, absent at south end ...	0	0 to	1	6	1	0 to	3	0
8. Pendle. Crystalline limestone, weathering slabby			2	0	0	0 to	1	0
7. Rubbly Limestone, variable, marly to massive (with thin, hard band locally above, up to 1 ft. thick)			4	0			4	0
6. Limestone, hard, massive, variable to gritstone	1	6 to	2	0			2	0
5. Rubble, variable, hard locally			3	6			4	0
4. Bottom Hard Band: Urchin Bed. Massive limestone, variable to gritstone or rubble. *Hyboclypeus wrighti* Étallon, *Perisphinctes* sp.			3	0			?	
3. Oyster Clay. Black, marly clay, with many oysters. *Exogyra nana*, *Serpulae*, *Chlamys* (*Radulopecten*) *fibrosa* (Sow.)			0	6			0	6
2. Shell Pebble Bed. Compact limestone, with many fossils mainly as casts. *Perisphinctes* (*Arisphinctes*) cf. *maximus*, *P.* (*A.*) *cotovui*, *P.* (*A.*) *pickeringius*, *P.* (*A.*) *laevipickeringius*, *P.* (*A.*) *plicatilis*, *P.* (*A.*) *helenae*, *P.* (*A.*) *vorda*, *P.* (*A.*) *kingstonensis*, *P.* (*A.*) spp. fragments, *P.* (*Dichotomosphinctes*) *antecedens*, *P.* (*Kranaosphinctes*) *decurrens*, *Cardioceras* (*Cawtoniceras*) *cawtonense*; *Nucleolites scutatus* Lamk., *Paracidaris florigemma* (Phillips) spines; *Pachyteuthis abbreviatus* Miller; *Pleurotomaria reticulata* Sow., *Bourguetia saemanni* (Oppel), *Procerithium muricatum* (Sow.), *Pseudomelania heddingtonensis* (Sow.), *Natica* (*Ampullina*) *arguta* Phillips; *Tri-*								

	SE. end		NE. end	
	ft. in.	ft. in.	ft. in.	ft. in.
gonia reticulata Agassiz, *Chlamys* (*Radulopecten*) *fibrosa* (Sow.), *Mactromya aceste* (d'Orb.), *Pleuromya uniformis* (Sow.), *Astarte ovata* Smith, *Isognomon subplana* (Étallon), *I. promytiloides* Arkell, *Gervillella aviculoides* (Sow.), *Exogyra nana* (Sow.), *Ostrea delta* Smith, *Gryphaea dilatata* Sow. var. *controversa* Roemer; *Serpula* spp. (large)		0 8		1 0
Berkshire Oolite Series (Beckley Sands)				
1. Gritstone		1 0		1 3
Sands, yellow, with layers of gritstone. *Cardioceras* (*Scoticardioceras*) *excavatum*; *Nucleolites scutatus* Lamk., *Chlamys* (*Radulopecten*) *fibrosa* (Sow.) seen		4 0		4 0

Of note is the apparent complete absence of the ammonite genus *Aspidoceras* from these beds.

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EASTER FIELD MEETING, 1952 : THE JURASSIC ROCKS OF OXFORDSHIRE AND THEIR SUPERFICIAL DEPOSITS

Report by the Directors: W. S. McKerrow, M.A., B.Sc., F.G.S. and D. F. W. Baden-Powell, M.A., B.Sc., F.G.S.

[*Received* 22 *October* 1952]

TWENTY-NINE members attended the meeting. The headquarters were at the Department of Geology and Mineralogy, University Museum, Oxford.

Thursday, 10 April

The Directors and Dr. K. S. Sandford gave a short introductory talk, explaining that the daily programme had been arranged stratigraphically rather than geographically.

Friday, 11 April

The Lias. Departing at 9.30 a.m. from the headquarters, the coach went northwards along Woodstock Road. On approaching Wolvercote Turn, the party observed the rise in the road from the Summertown terrace to the level of the Wolvercote terrace. The site of the Wolvercote channel was pointed out, although now entirely obscured by houses and gardens. Looking back over the Oxford Clay plain from the vicinity of Yarnton, the escarpments of the south-easterly dipping Corallian Beds, near Wytham and Beckley, were seen, while ahead lay the dip-slope of the beds of the Great Oolite Series. Between Woodstock and Chipping Norton, in the region of the outcrop of the Great Oolite Series, many narrow deep valleys occur in the plateau. The down-cutting of these rivers is due to Pleistocene movements, the net result of which was an uplift of up to 100 ft. (Sandford, 1924).

North-west of Chipping Norton, the road to Moreton-in-Marsh passes down into the valleys of the headwaters of the Evenlode and its tributaries which are floored by Lower Lias. The hills surrounding the Vale of Moreton were observed from a viewpoint near Little Compton. It was pointed out that the dominant scarp-features to the west, south and east of this Lower Lias vale were formed by three different sets of beds—the Inferior Oolite, the Great Oolite Series and the Middle Lias respectively. This was principally due to the south-easterly thinning of the Inferior Oolite (especially the Lower and Middle) and to the thickening of the upper part of the Middle Lias (Banbury Ironstone) in North Oxfordshire.

The first quarry to be visited was that of the Gloucestershire Brick Company Ltd. at Aston Magna; this village lies on the Oxford–Worcester railway line, two miles north of Moreton-in-Marsh. Here the uppermost beds of the Lower Lias are worked for brick-making, while in the higher parts of the quarry the lower beds of the Middle Lias are exposed.

In addition to capricorn Liparoceratids and many of the abundant lamellibranchs previously recorded from this quarry (e.g. by Arkell, 1947*a*, p. 17), a specimen of *Prodactylioceras davoei* (J. Sowerby) was collected. These ammonites indicate the presence of the zone of *P. davoei* (equivalent to the *capricornus* Zone of Wright).

Another interesting specimen collected by the party (but, unfortunately, not *in situ*) was a large block of clay with Lower Lias lamellibranchs which included many slightly worn limestone-pebbles. Dr. P. E. Kent suggested that the pebbles were possibly nodules formed in neighbouring Lower Lias deposits which were eroded soon after their formation, and that the specimen was thus indicative of local shallowing.

Before leaving this quarry, the party climbed to the highest point to look at the view, and to examine the rust-coloured sands and marls which crop out above the Lower Lias clays. These beds yielded *Amaltheus margaritatus* Montfort, the zonal fossil of the lower part of the Middle Lias.

From Aston Magna, the party drove to Stretton-on-Fosse, two miles to the north-east. At the pit south of the village, Dr. M. E. Tomlinson explained that the sand and gravel exposed here probably belongs to the Campden Tunnel Drift; this is believed to have been brought to the Moreton Gap from the north-west (Tomlinson, 1929). A good section was seen in pebbly sand, from which an interesting erratic was obtained; this has been sliced and proves to be a blue-green greywacke. A little limestone gravel and till were seen at the top of the section.

After lunch at Shipston-on-Stour, the coach proceeded eastwards towards Banbury, passing up on to the Banbury Ironstone escarpment east of Lower Brailes. After passing Sibford Heath (on an outcrop of Inferior Oolite), the coach turned south towards Hook Norton and across the Stour Valley trough, a down-faulted syncline in which beds of the Great Oolite Series crop out. No stop was made until the coach had crossed the fault to the south of this structure.

At a point 50 yds. south of the Gate Inn Cross Roads, one mile north of Hook Norton, the party left the coach and walked SSE. through Redlands Quarry. This was last visited by the Association in 1945 (Whitehead & Arkell, 1946), but the Banbury Ironstone is now no longer worked here, though good sections are still present in the south-eastern area.

The Ironstone, here about 20 ft. thick, represents the upper part of the Middle Lias (zone of *Pleuroceras spinatum*). No ammonites were found in this bed by the party (they are reported to be rare), but several brachiopod bands were observed, rich in specimens of *Rhynchonella tetrahedra* (J. Sowerby) and the terebratulid *Lobothyris punctata* (J. Sowerby).

The basal bed of the Upper Lias is a thin limestone composed largely of ammonite shells. It apparently represents a period of little sedimentation (see p. 91). The ammonites are assigned to the *Harpoceras serpentinum* Zone (Arkell, 1947*a*, p. 21); those collected include *Dactylioceras*, *Harpoceras*, *Hildoceras* and *Phylloceras*. The remainder of the Upper Lias consists of clay.

The next halt was to examine the Rollright Stones—a Bronze Age circle situated between the villages of Great and Little Rollright, and lying about four miles WSW. of Hook Norton. They consist of a sandy limestone which occurs locally where the Chipping Norton Limestone passes eastwards into the sands of the Swerford Beds.

The coach then proceeded to Chipping Norton for tea. The return journey to Oxford was made by way of Churchill, where the party examined the monument to William Smith, 'the father of English geology', who was born there in 1769.

Saturday, 12 April

The Upper Inferior Oolite and the lower part of the Great Oolite Series. The party left the coach at the southern end of Stonesfield village and walked south along the lane towards Stonesfield Ford. While still on the level of the Hanborough (or Handborough) terrace (here about 100 ft. above the river), the Directors drew attention to the incised meanders of the Evenlode Gorge; it was also observed that the present river was a misfit (the geology of the Evenlode Valley has been described in detail by Arkell, 1947*b*).

On going down to the ford, parts of the following lithological divisions of the Great Oolite Series were seen to be exposed on the floor and sides of the lane:

4. White Limestone
3. Hampen Marly Beds
2. Taynton Stone, with *Rhynchonella* Bed at base
1. Chipping Norton Limestone

The dip of these beds, seen to be towards the floor of the valley, is due to cambering.

At the top of the lane the Directors pointed out the tip-heaps of the old Stonesfield Slate mines. The slates immediately underlie the Taynton Stone, and were worked in the neighbourhood of the village by deep shafts through this bed. The restricted distribution of the slates is indicated by their absence in the lane leading to the ford.

From the foot of the lane, the party walked 50 yds. upstream to a steep bank by the river where Upper Inferior Oolite (Hook Norton Limestone and *Clypeus* Grit) was seen to overlie a grey-blue clay (Upper Lias). *Clypeus plotii* Klein and the terebratulid *Stiphrothyris globata* (*auctt. non* J. Sowerby) were obtained from the *Clypeus* Grit.

In marked contrast to the beds of the Great Oolite Series in the lane, these older beds are dipping steeply north-west, into the side of the valley. Arkell (1947*a*, pp. 150–1) describes the phenomena as due to valley-bulging, that is, he considers that the removal of the overlying limestones along the valley, and the resultant differential unloading of the plastic Lias Beds, are responsible for the upthrusting of these older beds (see also Hollingworth, *et al.*, 1944, p. 27).

The Upper Lias and the Lower Inferior Oolite both thin to the south-east in Oxfordshire; and in the Evenlode Valley, where the most south-easterly exposures of the pre-Bathonian Beds occur, the Upper Lias is very thin (*ca.* 10 ft.) and there is no Lower Inferior Oolite. The Upper Inferior Oolite behaves differently—it thins to the north-east in Oxfordshire, and is still over 20 ft. thick in the Evenlode Valley.

From the valley-bulge, the party climbed up a path to the west of the lane, and examined some tip heaps of Stonesfield Slate before returning to the coach.

At Fawler, 1½ miles north-west of Stonesfield, the Middle and Upper Lias and the Upper Inferior Oolite are exposed in an old ironstone quarry which was visited by kind permission of the owner, Mr. Crees, Manor Farm, Fawler. The general succession was still visible in spite of the overgrown condition of the quarry.

The basal bed of the Upper Lias is (like that seen the previous day at Hook Norton) a thin limestone crowded with ammonites. The species recorded from here (Woodward, 1893, p. 268, and Douglas, 1909, p. 196), however, include forms from higher zones of the Upper Lias in addition to those from the *serpentinum* Zone.

This bed at Fawler has previously been termed a remanié bed (Sollas, 1926), but this is perhaps not a very suitable name. An alternative explanation (which would seem more probable when the bed covers several square miles) is that the deposit is due to the long-continued presence of a body of calm water, rather than (as is implied by the term *remanié*) to the sifting of sediments by currents leaving a residue rich in ammonite shells. It would then follow that conditions of little sedimentation continued for a longer period in the Fawler area than in north Oxfordshire.

At Charlbury, the Evenlode Valley was seen to be much shallower than at Stonesfield; and the northward journey was continued to Chipping Norton, where a stop was made for lunch.

In the afternoon, the first halt was at Sharp's Hill Quarry, 5¾ miles north of Chipping Norton (337.358). Here, near the west end of the Stour Valley trough, beds of Upper Inferior Oolite and of the lower part of the Great Oolite Series are exposed. This quarry was visited by the Association in 1945 (Whitehead & Arkell, 1946), and was described in detail by Richardson (1911). The lithological sequence is:

	ft.	in.
4. Upper Sharp's Hill Beds (with *Viviparus* Marl at base)	6	2
3. Lower Sharp's Hill Beds	10	3
2. Chipping Norton Limestone	6	3
1. Hook Norton Limestone (with *Trigonia signata* Bed at top)	12	10

The *Trigonia signata* Bed (marking the top of the Inferior Oolite) and the *Viviparus* Marl were both easily recognised. The latter represents one of the more westerly extensions of the non-marine beds of Great Oolite age of Northamptonshire. The remainder of the Sharp's Hill Beds are marine, mainly clays and thin limestones. It will be observed that these beds, like the Stonesfield Slates, immediately overlie the Chipping Norton Limestone.

From Sharp's Hill the party travelled westwards, through Stow-on-the-Wold, to the Eyford district. Here two quarries were visited in the area of maximum development of the Stonesfield Slate facies (26 ft.). At Huntsman's Quarry (visited by kind permission of Messrs. R. and G. Hanks), 1½ miles north-east of Naunton, the stone is now quarried mainly for road metal; many of the beds are not sufficiently fissile to be used for roofing purposes. The party observed well-defined ripple-marks in shales on the quarry-floor.

The second stop in this area was at Kineton Thorns Quarry, half-mile to the north (123.263); here the beds are worked for roofing slates. Unfortunately, as it was a holiday, it was not possible to observe the craftsmen at work shaping the slates. This quarry proved to be more fossiliferous than Huntsman's Quarry; many perfect specimens of *Trigonia impressa* Broderip and *Lima cardiiformis* (J. Sowerby) are weathered out of the rock, and Mr. P. H. Phizackerley, the Local Field Meeting Secretary, identified a right ramus of the crocodile *Steneosaurus*.

The merits of *T. impressa* and other characteristic Stonesfield Slate fossils as horizon markers were discussed by some members of the party. As they no doubt constitute a facies-fauna, it was considered that they could not be used as reliable guides to horizon.

The party returned to Stow-on-the-Wold for tea and then travelled back to Oxford via Burford. A good example of an abandoned meander of the River Windrush was seen from the road between Burford and Witney.

Sunday, 13 April

The upper part of the Great Oolite Series and the Oxford Clay. Departing from Oxford by the Woodstock Road, the coach proceeded to Long

Hanborough by way of Bladon and the southern boundary of Blenheim Park. Leaving the coach at the Swan Inn, the party walked north-eastwards to Layshill Wood Quarry (which lies on the west of the River Evenlode). This quarry and the Swan Inn Quarry above it were visited by kind permission of Mr. J. Brown, The Malthouse, Long Hanborough. On entering the quarry, a solifluxion deposit was observed consisting of limestone fragments interdigitated with loam. The party then examined the White Limestone exposed in the quarry; although it is thicker here (*ca*. 50 ft.) than elsewhere in the district, no *Epithyris* bands are present.

Climbing up the hill over the partly exposed Forest Marble Beds, the party next examined the Cornbrash in the Swan Inn Quarry. This section has previously been visited by the Association in 1932 (Arkell, 1933) and in 1935 (Richardson, 1935); it is one of the few remaining complete exposures of the Cornbrash in Oxfordshire. The four zonal brachiopods were all obtained: *Cererithyris intermedia* (J. Sowerby) and *Ornithella obovata* (J. Sowerby) from the Lower Cornbrash, and *O. siddingtonensis* (Walker) and *O. lagenalis* (Schlotheim) from the Upper Cornbrash. At the west end of the quarry a small exposure of Kellaways Clay was found overlying the Upper Cornbrash and below the gravels of the Hanborough terrace.

The party then walked eastwards, crossed the road, and (by kind permission of Mr. Busby, Myrtle Farm) visited Smith's Pit in the Hanborough terrace-gravels. It was observed that the gravels are here resting on Lower Cornbrash; the Upper Cornbrash and basal Kellaways Clay must therefore be cut off to the south-east. A good view of the Evenlode gorge was obtained here. The party was reminded that the gorge can be dated by the facts that the Hanborough terrace caps the two sides, while lower terrace-gravels have been found in the present valley-bottom. The Hanborough gravels were not well exposed at the time of the visit, but the usual Bunter erratics were noted. In addition, an igneous erratic was found on the floor of the pit which, on slicing, proved to be an acid rock with some porphyritic plagioclase.

Rejoining the coach, the party drove through the village to Hanborough Station Quarry, quarter mile east of the station. The Forest Marble (Wychwood Beds and Kemble Beds) is here seen overlying the White Limestone. False-bedded, shelly, oolitic limestones of the Kemble Beds are worked for building stone (known locally as Bladon Stone). This stone has been used for the walling of the Geology Department and many other new Oxford buildings (see Arkell, 1947*c*, p. 114).

At the top of the White Limestone (Bladon Beds) there is a clay with lignite and *Cetiosaurus* bones.

The coach then proceeded north-east towards Enslow Bridge, and fine views were obtained of the Corallian escarpments and of the Chalk hills in the distance to the south. On reaching the Banbury road, the party proceeded north for one mile before turning right to obtain, three-quarters of a mile along this road, a good view of an abandoned meander of the Cherwell in which occur low-level gravels probably belonging to the Summertown terrace. While travelling to Kirtlington by way of Enslow Bridge, the incised meanders of the Cherwell were observed.

After lunch at Kirtlington, the party divided into two; one group proceeded down a lane west of the village to the Old Cement Works (495.200), and the other group examined a gravel pit to the north of this lane (497.200).

The Old Cement Works was visited by the Association in 1932, and has been described in detail by Arkell (1931). The beds present are:

Lower Cornbrash	
Forest Marble	Wychwood Beds Kemble Beds
White Limestone	Bladon Beds Ardley Beds

Three brachiopod bands occur in these beds in the Cherwell area; the shells are mainly those of the terebratulid *Epithyris*. Amendments to the lithological divisions since 1931 (e.g. Arkell, 1947*a*) place the three bands as follows:

Upper: in the Kemble Beds (only at the south end of the Old Cement Works, where it is 6½ ft. from the top).
Middle: in the Bladon Beds (3½ ft. from top).
Lower: at the top of the Ardley Beds.

Another amendment since 1931 is in the position of the *fimbriata–waltoni* Clay, a bed from which *Cetiosaurus* has been recorded; it is now placed at the top of the White Limestone. Specimens of *Astarte fimbriata* Lycett and *Gervillia waltoni* Lycett were obtained by the party, but no fragments of *Cetiosaurus* were collected during the visit.

The gravel-pit north of the lane to the Old Cement Works is not actively worked at present, and sections are rather poor. The gravel was demonstrated as belonging to the Hanborough terrace, with some later solifluxion at the top of the section. The erratics included a felspathic grit similar to Carboniferous types. No contemporary bones were found during this visit.

Both groups rejoined the coach at Kirtlington, and the party drove to Bicester and thence along Akeman Street to Woodham Brick Pit. Thanks are due to the directors of the Woodham Brick Company for allowing the party to examine this excellent Oxford Clay section. This pit and its ammonite fauna have been described in detail by Arkell (1939); an outline of the succession is given here:

ZONE	STAGE	DIVISION	LITHOLOGY
Q. mariae	Basal zone of the Lower Oxfordian	Lower part of Upper Oxford Clay	Clay (29 ft. seen)
Q. lamberti	Top zone of Callovian	Upper part of Middle Oxford Clay	Limestone, rich in ammonites (1 ft.)
P. athleta	Second top zone of Callovian	Lower part of Middle Oxford Clay	Clay (38 ft. seen)

From Woodham, the party returned to Bicester for tea.

The journey back to Oxford was made by way of Islip, situated on a complex inlier of the Great Oolite Series in the Oxford Clay (Arkell, 1944). The valley of the River Ray cuts a gorge through this inlier, providing a good example of superimposed drainage. From Noke Hill, on the south-eastern part of the inlier, the party observed the line of features made by the periclines of the Charlton (or Islip) anticline.

There was some discussion on the possible origin of this NE.–SW. fold. Some members, including Dr. P. E. Kent, considered that there might have been movement along an old fault-line in the Palaeozoic strata. Arkell (1947*a*, p. 141) points out that this line might extend for fifty miles to the north-east of Noke Hill, and it is of note that it would then exactly traverse an area where the Jurassic rocks are thinnest and the Palaeozoic strata less than 500 ft. below sea level (Kent, 1949; see also Falcon & Tarrant, 1951, pp. 161 and 169). Arkell's observations (1944, p. 72) that many of these periclines have a faulted or steeply folded, southern limb suggest that, if this is an old fault-line, the latest movement has been a downthrow to the south-east.

From Noke Hill the coach crossed south-eastwards over 'the narrowest outcrop of Oxford Clay on record. . . . Much of it must be faulted out' (Arkell, 1944, p. 66). The return journey was made along the Corallian escarpment to Elsfield, and then down through Marston to Oxford.

Monday, 14 April

The Corallian, Kimmeridge and Portland. Departing from the centre of the town by Magdalen Bridge and St. Clement's, the coach climbed up to Headington, the eastern suburb of Oxford which lies on the Corallian escarpment. The first stop was at the Cross Roads Quarry (to the north-west of the intersection of Old Road and Windmill Road). Here coral-bearing horizons of the Upper Corallian are interdigitated with detrital beds rich in *Exogyra nana* (J. de C. Sowerby). The most abundant corals found were species of *Isastraea* and *Thecosmilia.*

From Headington the party drove 2½ miles north to Messrs. Benfield and Loxley's quarry, half a mile south of Beckley. This quarry was visited by the Association in 1951 under the directorship of Messrs. J. M. Edmonds and J. H. Callomon (Callomon, 1953). Here 24 ft. of Beckley

Sands are exposed, and overlain unconformably by some rubbly and marly limestones. The three main divisions in the Oxford Corallian recognised by Arkell (1927 and 1947*a*) are:

Osmington Oolite Series
Berkshire Oolite Series
Lower Calcareous Grit

Although the Beckley Sands are lithologically similar to the Lower Calcareous Grit, Arkell considers (1947*a*, p. 96) that they belong to the Berkshire Oolite Series, and that the overlying limestones (like the Oxford Coral Rag) are of Osmington Oolite age.

The next halt was at Warren Farm, Studley, three miles north of Beckley. Here, by kind permission of Mr. J. K. Henderson, the party examined a small outcrop of the Arngrove Stone in a pit at the southern corner of Whitecross Green Wood. This rock occurs locally at the base of the Corallian; it is composed of minute globular siliceous spicules of the sponge *Rhaxella perforata* Hinde. Among the fossils obtained from this site is the ammonite *Cardioceras* (*Vertebriceras*) *vertebrale* (Sow.).

From Studley, the coach went south-east, by Stanton St. John and Forest Hill to Lye Hill Quarry (592.072), where a marked depositional dip was observed in the Wheatley Limestone (Arkell, 1947*a*, p. 97); these beds are the detrital equivalents of the Coral Rag.

The next stop was at Littleworth Brick Pit, Wheatley, where Kimmeridge, Portland and Wealden Beds were examined. The succession here is compared with that at Cumnor below.

After lunch in Wheatley, the party returned to Headington, and then turned south, through Cowley to Littlemore. In Littlemore Station siding (to the west of the station) sands and doggers of the Lower Calcareous Grit are exposed. They are overlain by marls and limestones which contain Upper Corallian *Perisphinctes* spp. Arkell therefore considers these Littlemore Clay Beds to be argillaceous equivalents of the Coral Rag and the Wheatley Limestone. Large masses of *Exogyra nana* (J. de C. Sowerby) occur in many places.

From Littlemore the party returned to Oxford for tea. After tea the President, Dr. G. W. Himus, proposed a vote of thanks to the Directors.

The party then drove to Cothill (five miles west of Oxford), and, by kind permission of Amey's Aggregates Ltd., examined the quarry a quarter of a mile east of the village. Here the full Corallian succession of the Oxford district is visible:

Osmington Oolite Series: Coral Rag
Berkshire Oolite Series: sands, clays and limestones, with pebble bed at base
Lower Calcareous Grit: sands and grits with doggers

This quarry was visited by the Association in 1931.

From Cothill the coach went three miles north to Cumnor, where the rather overgrown sections of the Chawley Brick and Tile Works were examined. It is interesting to compare the succession here with that seen at Wheatley only 7¼ miles to the east (see below). The differences are no doubt due to the proximity of Oxford to the northern margin of the basin of deposition from Portland to Lower Greensand times.

	CUMNOR	WHEATLEY
Gault	Disturbed remnants below Plateau gravel	—
Lower Greensand	Sands with ironstone concretions (no fossils)	—
Wealden	—	Shotover Sands (non-marine)
Purbeck	—	—
Portland	—	Sand above, limestone below
Upper Kimmeridge	Sandy clay (upper part absent)	Mainly sands
Lower and Middle Kimmeridge	Clays	Clays

A comprehensive view of the Oxford area and the surrounding escarpments is normally obtained from the summit of Cumnor Hurst above Chawley Brickworks, but the visibility was very limited owing to rain.

From Cumnor the coach returned to Oxford, and the meeting concluded about 6.30 p.m.

The Directors would like to thank Dr. Sandford for his assistance at this meeting, and Dr. W. J. Arkell for helpful suggestions and criticism in the preparation of this report. Thanks are also due to Dr. M. E. Tomlinson for describing the section at Stretton-on-Fosse.

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FIELD MEETING AT FRANKLEY AND RUBERY, 2 June 1951

Midland Group

Report by the Director: Frank Raw, D.Sc., F.G.S.

[*Received* 20 *November* 1952]

THE route followed by the party was from Allen's Cross (Borrowdale Road) by Egg Hill Lane to Frankley Beeches on the Stour–Rea, or Tame, watershed; along this to Newtown Farm and thence to Rubery for tea.

At the first halt on Keele Beds attention was directed to the relics of the upland plain between 600 ft. and 700 ft., with the ground rising from it to Warley and the Lickey, Frankley and Clent Hills. Below this, on either side of Frankley Church, the Frankley and Bartley Reservoirs store water from Wales.

From thence the party passed over Enville Beds to Frankley Beeches on Enville Breccia, situated *ca*. 840 ft. O.D., and overridden by ice in Pleistocene times. Here, on the watershed, the Director pointed out the marked contrast in the thalwegs between the tributaries of the Tame to the east, and the Stour, tributary to the Severn, to the north-west. He expressed a personal view that the upper slopes of the Stour basin were those of a pre-glacial higher Stour, which had flowed to the Irish Sea, its present lower course being, on this view, a glacial diversion. Its rejuvenation he attributed to the enormously increased volume of water now going to the Bristol Channel, as compared with the pre-glacial Avon and Stour.

From here, by road and field, the route led to the lowest part of the watershed that is cut through by the railway; a greater number of erratics, among which big Bunter pebbles, Arenigs, vein-quartz, quartzite and Rowley Rag were conspicuous.

The railway cutting showed about 15 ft. of loose, yellowish sand on Enville clays and sandstones. To the south-west, in two large pits extending for a quarter of a mile, about 20 ft. of similar sand without pebbles and resting on clay had been exploited pre-war for building. The railway cutting also shows some boulder clay. The pits are now being filled up with clay, presumably Keele, from Austin's Works. The sand extends to the watershed and some continuation has probably been removed by denudation. A similar pit south-east of Newtown Farm was also visited.

The rather even slopes, gently descending south-east from the watershed and consisting of loose sand resting on Enville clays, were interpreted by the Director as deposition slopes, formed by a glacial overflow from the Upper Stour basin to that of the Rea, due to the damming up of the former by ice from the north-west in the waning stages of the last local glaciation. The lowest part, on both sides of the railway, would be the latest channel; and the north-east bank of this glacial river is suggested by a rise bounding the sand plane. The theory seemed to be accepted by the members as probable.

FIELD MEETING AT WELSHPOOL

Midland Group

Report by the Director: Miss E. M. Hignett, B.Sc.

[*Received* 30 *November* 1952]

Friday, 4 May 1951

THE party, which numbered thirty-six, assembled at the Royal Oak Hotel, Welshpool, and after dinner an introductory talk was given. It was shown that the area to be visited consisted of Caradocian and Silurian rocks folded into two parallel anticlines with north-north-easterly and south-south-westerly axes, the eastern anticline occupying the Severn Valley and the western the valley of the Guilsfield Brook. These Palaeozoic rocks, generally dipping at high angles, consist mainly of beds of shales alternating with resistant grits which form the characteristic sharp tree-covered ridges of the area. Igneous intrusions stand out as bold features, the most noteworthy being the Breidden Hills, often called 'The Gateway to Powys' on account of their almost sheer rise from the flat country of the plain of Shropshire. Other smaller intrusions are the Welshpool Dyke, seen at the western end of the town, and the Cefn intrusion near Buttington Brickworks.

After the Caledonian orogeny, peneplanation took place, followed by the accumulation of further deposits and a tilt to the east which was responsible for the course of the rivers. These newer rocks have since been eroded and the drainage is superimposed on the Palaeozoic rocks, the river-valleys being deep and narrow where the rivers are forced to cut across the grain of the rocks, but opening out into broad, fertile valleys along those stretches where they are coincident with the strike of soft shale-bands, as in the centres of the Vale of Guilsfield and the Severn Valley anticlines.

It was pointed out that Upper Coal Measures outcropping from north to south would be seen to rest unconformably upon Caradocian shales in the Bausley district, though, as both series are of a soft, shaly nature, no noticeable land-feature occurs at the junction. Farther north, however, where the Millstone Grit is present at the base of the unconformity, its westward-facing escarpment forms a line of vantage used by King Offa in the construction of his defensive dyke.

Saturday, 5 May

The first stop was made at Buttington Brickworks where Buttington Shales are being quarried. These beds consist of green and purple shales with a few flaggy bands rising almost vertically against the Cefn intrusion.

From their position and lithological character these beds, which are unfossiliferous, are inferred as being of Tarannon age. The party was conducted around the brickworks by the manager, Mr. Mannifield, who gave an interesting demonstration of the making of bricks and pipes from Buttington Shale.

The excursion then continued along the north-western foot of the Breidden Hill, the next stop being made in the large quarry of the British Quarry Company, where the dolerite of the intrusion is worked for road metal and gravel. The dolerite was found to be markedly vesicular in places, particularly along the joints. A striking feature of this side of the hill is the almost sheer declivity by which the land drops from 1202 ft. at Rodney's Pillar to about 200 ft. in the water meadows of the Severn.

From the road-stone quarry the excursion was continued eastwards to Bausley, whence the party walked over Bausley Hill to Bragginton Dingle. In this region the Ordovician rocks are markedly different in character from those of the Welshpool area, though probably of practically the same age. They consist mainly of volcanic conglomerates and tuffs interbedded with shales, the Upper Volcanic Group of the Caradocian giving rise to the feature of Bausley Hill. Leaving the road by Bausley Chapel and walking over the hill, the party crossed successively lower beds of the Caradocian until reaching the large Bragginton dip-fault, which brings Upper Coal Measures on the east against the Ordovician rocks to the west. On the east of the fault, however, the erosive work of a small stream in Bragginton Dingle has uncovered a small area of Ordovician rocks, presumably the youngest in the district lying immediately underneath the Upper Coal Measures (the Ruabon Marls). These Ordovician rocks were red shales probably stained by water percolating through the overlying Ruabon Marls and, upon examination, yielded numerous fragments of *Trinucleus* sp. (*s.l.*). Following the bed of the stream eastwards, the character of the rocks exposed was found to change and, from pale grey shales, many leaves and stems of Coal Measures plants were collected, including *Neuropteris scheuchzeri* Hoffman, *Annularia stellata* (Brongt.), *Alethopteris serli* (Schloth.) and *Lepidodendron* sp. Still farther downstream specimens of poor quality coal and *Spirorbis* limestone were collected.

The party then drove past Prince's Oak to Halfway House and thence to Long Mountain, via Westbury and the Forest of Hayes. Long Mountain, a synclinal feature, is composed mainly of Silurian rocks with a small outlier of Devonian rocks on the top of the ridge in the Forest of Hayes. The exposure here proved to be of poorly fossiliferous micaceous sandstone which yielded eurypterid fragments and *Lingula* sp.

The party then drove along the Roman Road which runs north-east–south-west along the crest of Long Mountain, and was probably constructed as a supply line to Roman exploiters of the Cardigan lead deposits.

Descending from Long Mountain by Harp Hollow, where the Cletterwood Brook has cut a deep ravine into the steep westward-facing slope of the mountain, the party was able to see how afforestation is being carried out in order to check soil-erosion in the gully. Just above Cletterwood Mill a halt was made in order to examine shales of Ludlovian(?) age which are exposed in an old quarry to the right of the road. The exposure proved to be very fossiliferous and yielded good specimens of *Monograptus* spp., *Atrypa reticularis* (Linn.), *Wilsonia wilsoni* (J. Sow.), *Cardiola interrupta* J. de C. Sow., *Euomphalus* sp., *Orthoceras* sp. and *Conularia* sp. The party then returned via Buttington to Welshpool, where tea was taken at the Royal Oak Hotel.

Sunday, 6 May

On Sunday the party visited the western edge of the Vale of Powys to examine the Ordovician and Silurian rocks exposed on the northern limb of the Guilsfield Brook anticline. The first stop was made at Bron-y-Buckley within the boundaries of the borough. A small stream in Bron-y-Buckley woods cuts a fine strike-section through the Trilobite Dingle Shales, which are the oldest rocks exposed in the Welshpool area and are placed by Wade as of Glenkiln–Hartfell age. This dingle was described by Murchison, who named it 'Trilobite Dingle' on account of the large number of *Trinucleus concentricus* Eaton which he collected there. The party was able to collect many good heads and a few almost complete individuals of *Trinucleus* (*Salterolithus*) sp. and other fossils, mainly orthids. To the west of the dingle, the shales abut against the Powys Castle Conglomerate, which forms the wall of Welshpool dyke, while to the east near the entrance to the woods shales yielded specimens of *Monograptus* sp., indicating that in the dingle the Trilobite Dingle Shales must represent a horst thrust up between two north–south faults each of considerable throw.

Driving towards the Guilsfield road the party passed a large quarry in the Welshpool Dyke of bostonite, which intrusion was worked until the early part of this century to provide building stone for the town.

The party then proceeded via Guilsfield to Sarn Bridge. Here the Guilsfield Brook running along the strike of Trilobite Dingle Shales exposed in the centre of a north-east–south-west anticline, forms a broad valley bounded on either side by rising land formed by the scarps of the more resistant overlying grits. A tributary of the Guilsfield Brook, entering it near Sarn Bridge and running roughly at right angles to the main stream, cuts across all the Ordovician rocks exposed to the west of the anticline, thus forming a good dip section of the whole sequence. As it cuts across bands of varying resistance, this valley of Gwern-y-Brain, unlike the broad valley of the Guilsfield Brook, is deep, rocky and ungraded, thus providing many exposures, while at the same time emphasising the essential contrasts in the geomorphology of the superimposed valleys of the district.

The party followed a lane alongside the stream. The lowest Ordovician rocks of the district, the Trilobite Dingle Shales, which had already been examined in the type locality, are not well exposed in Gwern-y-Brain owing to the overlying drift, but as the lane climbed a little, the splintery shales and flags of the Pwll-y-glo (Coal-pit) group could be examined in small road-side exposures. Some of the grits were micaceous and the beds were not very fossiliferous, although some specimens of *Orthis* (*s.l.*) were noted.

At the foot of the bold escarpment of Gaer Fawr (Great Camp) a quarry in the massive grits with shaly partings exposed the Gaer Fawr beds in their type area. Along certain bands these grits are richly fossiliferous and yielded specimens of *Orthis* (*s.l.*), *Rafinesquina* and *Strophomena*.

Climbing the steep scarp-slope of these grits, the party crossed the ancient earthworks and ditches of a Bronze Age fort to reach the top of Gaer Fawr Hill, and took lunch at the top of the eastward-facing scarp-slope looking out across the low ground of the Vale of Guilsfield representing the top of an anticline, and towards the higher ground of Yr Allt, where massive flags of Ludlow age are brought in by the syncline.

Leaving the fort through the ancient gateway at its northern end, from which was obtained an extensive view of the plain of the Severn with its bastion of the Breidden rising steeply on the farther side, the party descended Gaer Fawr Hill on its western side, and made its way across a stretch of low pasture representing the outcrop of the Gwern-y-Brain Beds —the highest Ordovician rocks of this district.

In a rise beyond this low ground a halt was made to examine an outcrop of Powys Castle Conglomerate, the basal bed of the Silurian Series, which may be found throughout the district resting in turn upon every member of the Ordovician sequence. In this locality it was found to be a coarse conglomerate containing pebbles of quartz, jasper and fine-grained igneous rock, and from its deep-red colour is apparently highly ferruginous. Wherever this conglomerate occurs in the district, it forms bold features such as Powys Castle Hill, the castle itself being built of and upon this rock, its red colouring presumably giving the castle its early name— Castell Coch (Red Castle).

Reaching a lane, the party turned eastward to work back down the sequence towards Sarn Bridge. Outcrops of Powys Castle Conglomerate were again seen in the roadway on a steep hill and, at the foot of the hill near a small spring, some limestone beds, probably part of the Gwern-y-Brain Series, were examined and yielded numerous brachiopods.

Further exposures in the Gwern-y-Brain Series were examined on the other side of the brook in Trawscoed Rough. Here the Gwern-y-Brain Beds, which are exposed in the stream-bed and in small workings in the rough, are characteristically thin fine-grained jet-black shales, which yielded *Diplograptus* sp., *Orbiculoidea perrugata* (M'Coy), *Orthis* (*s.l.*), *Lingula* sp., and *Trinucleus* cf. *seticornis* (His.). The brook was then followed back to Sarn Bridge, past several good exposures in the Gaer Fawr and Pwll-y-glo Series.

At Sarn Bridge, Professor Shotton expressed the thanks of the Midland Group to the Director for two days' fine geology; to Miss Macnair, who had helped in the preparation of the excursion, and to Mr. A. Ludford who, as secretary, had been responsible for making all the arrangements.

The excursion was then continued to the Groes and then along a road practically coincident with the Moel-y-Garth fault which, being a dip fault, is responsible for a considerable lateral displacement. Consequently Gaer Fawr Grits on the southern side formed the bold ridge of Moel-y-Garth Hill, while to the north the soft Ludlow Shales form low farmland.

A halt was made in a road-side quarry near Maesmawr school in order to examine an exposure of Ludlow Beds on the western side of the Vale of Powys. Here they consisted of blue flagstones from which were collected a few specimens of *Monograptus* sp. and brachiopods. The party then returned via the Cloddiau and Groes Pluen to Welshpool and, after tea at the Royal Oak Hotel, dispersed.

EROSION-SURFACES AROUND DIEPPE

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SUMMARY.—In order to compare the erosion-platforms of Southern England with those of Northern France a survey of some 600 sq. mi. of the Chalk near Dieppe was carried out. Below an upper surface at 790–690 ft., marine platforms were traced at 660 ft., 535 ft., 485 ft., 435 ft., 380 ft., 330 ft. and 240 ft. They correspond very well in elevation with the platforms of Southern England, the Channel Islands and North-western France. It appears, as a result, that the western part of the English Channel is quite an old feature, dating at least from the Pliocene, although the shoreline has, as would be expected, changed somewhat in detail.

1. INTRODUCTION

THE analysis of dissected erosion-surfaces is a study as popular with English geomorphologists as it is unpopular with the French. Such study has two main objects: the detailed evaluation of local denudation chronologies and the elucidation of the nature of movements of base-level over wide areas. With the second object in view, it was decided to survey an area of the Chalk of North France, as no French studies of the required type are available. The area surveyed extends from St. Valery-en-Caux to the River Yères, a distance of thirty miles, and stretches inland some eighteen miles in the west and thirty miles in the east. It possesses several advantages: it has a considerable range of elevation from 800 to 200 ft.; it exposes beds ranging from Upper Jurassic to Lower Tertiary in age and there is, therefore, the possibility of demonstrating conclusively that the platforms are erosional; it is sufficiently large to enable one to discount the possibility that the various remnants of plateau, found consistently at similar elevations, are freaks produced by the dissection of a single surface; finally the region is reasonably accessible from Dieppe.

2. STRUCTURE AND TOPOGRAPHY

The area is the structural continuation of the Mesozoic area of southern England, but the mid-Tertiary fold-axes change direction from west–east to north-west–south-east (King, 1948, pl. 17). In France, as in southern England, the folds are asymmetric, the steeper dips being on the north-east limbs of the anticlines. The major fold is the Bray anticline, the northern half of which is within the area studied. Its axis is indicated approximately by the course of the River Béthune (Fig. 1), which has carved out an extensive anticlinal vale exposing Upper Jurassic rocks. The complementary Aliermont syncline to the north-east is also inverted in relief as it forms the high Chalk interfluve between the Rivers Béthune and Eaulne. Other minor folds in the area have little effect on the relief. The same is true of numerous small faults, which have yet to be proved to affect the relief inland, although they are quickly etched out by the sea in the face of the cliffs.

The Chalk plateau is mainly covered by later deposits. Various outliers of Lower Eocene rocks are mapped: the largest is on the coast west of Dieppe at Varengeville, where the unkempt landscape of pine, birch and scrub contrasts markedly with the arable cultivation of the *limon*-covered[1] Chalk. Elsewhere the Chalk surface is extensively piped to a maximum depth of 20 ft. The pipes contain a rubble of iron-stained flints and oxidised clay and loam. Some of the pipes contain large, fine-grained quartzitic sarsens up to 8 ft. in length. These are well displayed in pipes in the cliffs at Veules-les-Roses. Piping on such a scale probably indicates, as it does in Southern England, proximity to the base of the Eocene.

The whole of the region, with the exception of some of the steeper valley-sides, is mantled with *limon*. The thickness of the *limon* is not known in detail. The greatest thickness seen was 15 ft. in a shallow, infilled valley exposed in the cliff-face, while inland brickworks sections exposed 6–8 ft. without reaching the Chalk. As it was formerly the custom of the farmers to dig through the *limon* for Chalk for dressing their fields, it is probable that the normal maximum thickness of the *limon* is no more than 10 ft.

In broad outline, the area is a plateau reaching 800 ft. around the Bray anticline and 600 ft. inland in the west. The plateau slopes seawards down to 200 ft. in the west and 300 ft. in the east. It is scored by a number of valleys, the larger occupied by streams which flow northwards in the west and north-westwards in the east. Numerous dry valleys of a variety of types are tributary to the main valleys.

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[1] *Limon* is an unbedded, buff, calcareous silt, which is often attributed to wind deposition in the Pleistocene period.

3. METHODS OF SURVEY

The accuracy of this type of investigation is governed largely by the accuracy of the available topographic maps. There is no French equivalent of the British 6-inch map, but I was fortunate in being able to borrow a series of British Army maps on a scale of 1: 25,000. These are based on French maps and supplemented by air-survey. They are contoured at ten-metre intervals and show the spot heights of the French survey. Neither contours nor spot-heights are as accurate as one would wish. In an adjacent region, de Lamothe (1918) found 6 m. (19 ft.) errors in some of the spot-heights, and I am convinced that occasional errors of as much as 30 ft. occur in the area studied.

The surveying was done with aneroid barometer and Abney level, and every effort was made to cross-check elevations when doubt was felt about the spot-heights on which traverses were based. It is believed that most of the elevations quoted are reasonably correct, but the possibility of errors up to 20 ft. cannot be excluded.

In the field, the presence of small woods and tree-belts, especially in the west, rendered observation somewhat difficult. The platform fragments are often recognisable only after one has plotted a series of partial views on a map. The geographical characteristics of the area are those of *limon* and there is little of the bareness of many of the English Chalk areas, which are ideally suited to the recognition of erosional platforms.

4. THE EROSION-SURFACES (Fig. 1)

The average slope of the land towards the sea is approximately 20 ft. per mi. In spite of this gentle gradient, it is visibly not a single surface but a series of broad shallow steps. To be recognisable in such conditions platforms must be very flat indeed. Typical gradients on features thought to be remnants of marine platforms are of the order of 3–10 ft. per mi. The intervening breaks of slope may have gradients of only 25–50 ft. per mi. Nevertheless, the recognition of such differences by eye in the field is quite easy. The altitudinal grouping of the flattenings over the whole area is so marked that it can be concluded that the flattenings are the remnants of erosional platforms, which are considered in more detail below. For the time being the full range of elevation of all fragments included within each platform is quoted.

(a) **The 790–690-ft. platform (240–210 m.).** The highest platform in the region is one of the most obvious. It is extensively developed on the Chalk rim of the eroded Bray anticline around Neufchâtel-en-Bray (4745).[1] and reappears, east of the River Eaulne, again on the Chalk. Of great importance are three Portlandian summits near Gaillefontaine (5935), as they reach the elevation of the surface and, thus, suggest that it is of an erosional nature. They also show that the surface must post-date the folding of the Bray anticline.

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[1] Grid references enable places to be located easily on Fig. 1.

There can be no conclusive argument as to the origin of the platform. The drainage within the area now occupied by the platform is of a subsequent nature. To this indication of a sub-aerial origin, it may be added that the only good examples of clay-with-flints, a thick deposit of rusty clay and angular flints, were seen on this platform in the Forêt du Hellet (4550). The inferior quality of the soil, when compared with the fertile *limon*, is indicated by a higher percentage of woodland, an increased proportion of permanent grass and oats, and a decreased proportion of wheat and sugar-beet cultivation. Such facts are an indication of a sub-aerial surface, or, at least, a marine surface which has undergone a long period of sub-aerial weathering.

(b) **The 660–560-ft. platform (201–170 m.).** This is one of the most important in the region. It extends in the south-west, between Yvetot and Saint Saëns, for some 20 mi. within which practically every summit reaches the elevation of the platform. A restricted view of the area shows no clear-cut break between this and the highest platform, because the break of slope has been largely destroyed by the headwaters of the River Varenne between Saint Saëns and Buchy. However, if one takes a broad view of the country south of Saint Saëns, one may see that the highest platform is not a continuation of the 660-ft. platform, unless the former has been warped in a step-like manner. The same result can be obtained by drawing generalised contours on the map.

Smaller fragments of the platform, the largest about 5 mi. in length, are found on the Chalk to the north and east of Londinières (4556). At Smermesnil (5157) a marked break of slope separates the highest platform from the 660-ft. platform. Within the Bray fold, an isolated flat-topped ridge west of Bures (4051) suggests that erosion was facilitated along the line of the anticline.

(c) **The 535–500-ft. platform (163–153 m.).** The maximum development of the platform is in the region round Auffay and Tôtes, west of the River Varenne. East of that river the platforms disappears as it has been overrun by lower and more recent platforms. The break of slope between the 660-ft. and 535-ft. platforms is nowhere easily observed. To the south-west of Bellencombre, the view from a fragment of the 660-ft. platform (3040) shows that the 535-ft. platform is probably distinct, and the same can be seen in general fashion around Tôtes (1841). The surviving remnants of the 535-ft. platform are large, that to the east of Auffay on the Varenne-Scie interfluve being some eight to nine miles long, slightly dissected and ranging from 535 to 510 ft. in elevation. Similarly, there is a seven-mile-long platform at 530–505 ft. to the north-west of Tôtes (1841).

(d) **The 485–460-ft. platform (147–140 m.).** The 485-ft. platform is of smaller importance than the main platforms at 790 ft., 660 ft., 535 ft. and 330 ft. Nevertheless, important fragments indicated on the map have been preserved, that to the north-east of Envermeu (3664) being two and a half miles long, while, to the north-east of Doudeville (0351), there is a platform, two miles long, at 480–470 ft. The break of slope from the 535-ft. platform is not easy to trace: it is probably preserved on the Varenne–Scie interfluve, east of Longueville (2753), but is hidden by woodland and buildings.

(e) **The 435–405-ft. platform (133–124 m.).** The distribution of fragments of this platform is sporadic. In the far west, north of Doudeville (9753), an important fragment, nearly three miles in length, is quite distinct from the lower platforms and separated from the 485-ft. platform to the east by a gentle but visible break of slope. Eastwards the platform is not well developed, apart from a dissected remnant between Bacqueville-en-Caux and Longueville (2053), until the Varenne–Béthune interfluve is reached. Here, the Bois du Pimont (3158), an isolated flat-topped ridge some two miles long and comparable in form with the 660-ft. platform to the south-east, again points to the inland extension of a platform along the line of the Bray anticline. North-east of Dieppe (3571), a fragment at 430–420 ft. and over a mile in length, is clearly distinct from the 485-ft. platform to the south.

(f) **The 380–365-ft. platform (116–111 m.).** Only four flattenings occur at this elevation, but as they are up to 1000 yds. in length they may be fragments of a former erosion-surface.

(g) **The 330-ft. group of platforms (347–270 ft.; 106–82 m.).** The title is chosen deliberately as there are certainly two and possibly three platforms at closely spaced intervals. Together they form the dominant lower platform of the Chalk of this part of Northern France. The composite platform occurs in a band some four to eight miles broad along the coast, except in the west where fragments of an even lower platform are found and in the east where higher ground reaches the coast. The belt occupied by the 330-ft. platform is dissected but, within it, very extensive remnants are found. Ignoring small fragments of less than 1000 yds. in length, one may note areas such as those east and west of Dieppe. Offranville (2062) is situated on the eastern end of a plateau which is approximately three miles long and ranges from 306 to 270 ft. South of Offranville are other fragments up to a mile in length, while, north of Offranville, all the coastal summits, whether cut into the Chalk or the Tertiary, attain the same elevations. It is obvious that this region, some eight miles long by four wide, is nothing more than a portion of dissected 330-ft. plateau. Again, immediately east of Dieppe, a portion of the same surface at 345–315 ft. is over 5000 yds. in length. In the north-eastern corner of the region studied another large fragment of the platform is to be found (3973): it is three miles long and has a breadth of one mile if dissection be ignored. There is an obvious break of slope between this platform and the higher platforms to the west, although it is difficult to fix the rear elevation of the lower platform because of the gradual flattening of the slopes.

It will be noted from the foregoing that the remnants of the 330-ft. group of platforms tend to occur either a little above or a little below 300 ft. There were probably three stillstands at close intervals, but it is not possible, especially with the errors inherent in the maps, to attempt to trace them as entities throughout the region. In several places they may be separated tentatively. South of St. Valery-en-Caux (9858), a 900-yds. long flat at 276–270 ft. is clearly separate from a 2800-yds. long flat at 347–340 ft. At Ambrumesnil (1760) a 2000-yds. long flat at 285–275 ft. is separated by a slight break of slope from a 1000-yds. long flat at 334–328 ft. to the south. A similar occurrence is found at Avremesnil (1260), where a small plateau, 1500-yds. long at 290–285 ft., appears to be distinct from a 1000-yds. long flat at 330–320 ft. to the south. Again, east of Dieppe, the broad plateau mentioned above appears to be composed of two minor stages, one at a little above 340 ft. and the other at 330–315 ft. From this evidence it is probable that there are platforms with backs at *ca.* 290 ft., 330 or 335 ft. and 345 ft. But, for reasons stated above, they are here combined as the 330-ft. group of platforms, as that is usually the highest elevation attained.

(h) **The 240–185-ft. platform (73–57 m.).** The platform is found only in the west of the region studied, where it occurs between St. Valery-en-Caux and the mouth of the River Saâne. At its maximum it attains a breadth of some two miles and includes some notable fragments, especially that immediately west of Quiberville (1166). Only seven fragments of the platform survive and, thus, it is impossible to be sure whether the platform is composite. The flats do tend to occur either at 240–230 ft. or at 210–185 ft. Combined with the following evidence this indicates a probable composite nature. At la Chapelle-sur-Dun (0663) two flats, each a little less than 1000 yds. in length, at 240–235 and 210–200 ft. are separated by a noticeable break of slope.

All platforms below this elevation are precluded by the height of the present line of cliffs.

In the Dieppe region it may be concluded that the following erosional platforms are to be found. They are defined, except for the highest subaerial platform, by the height of their landward margins, as, for reasons stated below, they are thought to be marine.

(1) 790–690-ft. (240–210 m.)
(2) 660-ft. (201 m.)
(3) 535-ft. (163 m.)
(4) 485-ft. (147 m.)
(5) 435-ft. (133 m.)
(6) ? 380-ft. (116 m.)
(7) 330-ft. (101 m., including minor stages at 347, 330 and 290-ft.)
(8) 240-ft. (73 m., probably including minor stages at 240 and 210-ft.)

5. ORIGIN OF THE PLATFORMS

There is no possibility that the platforms are structural in the strict sense or structural surfaces exhumed by erosion. The rocks are folded along NW.–SE. axes, but the platforms are horizontal and step, in one or two places, from Chalk to newer and older rocks. The highest platform has already been considered as sub-aerial, because of the thick mantle of residual deposits found on it. The argument is the same as that used by Wooldridge & Linton (1939) in discussing the mid-Tertiary peneplain of South-east England.

The lower platforms are all of the same type and their origin may be discussed generally. They are covered with a blanket of *limon*, which effectively masks whatever gravel may exist on the surface of the Chalk below. One or two patches of gravel seen were so heterogeneous and disturbed that no conclusions may safely be drawn from them. The French 1: 80,000 geological maps show a covering of clay-with-flints beneath the *limon*, but the writer suspects that the covering is by no means as complete as is shown. Wherever the Chalk could be inspected in cliff- and quarry-sections, a rubble of flints was usually found to be piped into the Chalk, but there did not appear to be a bed of clay-with-flints. As the solution and piping may have occurred at any time since the Eocene, the so-called clay-with-flints cannot be considered as indicating a sub-aerial origin of the surfaces.

The only other criterion normally used for judging the origin of platforms is the nature of the relation between streams and structures. The use of this criterion is complicated in the Dieppe region by the fact that the general orientation of the drainage-pattern is that which would result either from the development of subsequent streams or from superimposition from shorelines approximately parallel to the present coastline. Fortunately the course of the River Béthune is somewhat anomalous. It follows the line of the Bray anticline but continues to flow north down the pitching end of the fold. The fold has disappeared before the present coastline is reached. Such a course is not that to be expected normally in the development of anticlinal drainage. A true subsequent stream would probably have developed from a lateral consequent draining the flank of the anticline at its greatest amplitude, i.e., in the south of the area under discussion. The subsequent stream developed from this lateral consequent stream should have eroded headwards towards Dieppe but flowed southwards towards Neufchâtel-en-Bray. On the other hand, old shorelines would probably have had embayments where the weaker beds in the anticline were exposed to marine erosion in the cliffs. Embayments are shown on the reconstructed shorelines (Fig. 1). The shorelines are drawn to indicate the minimum embayments consistent with the distribution of platform-fragments. A series of superimpositions in such embayments is probably sufficient to account for the way in which the Béthune flows down the pitching end of the Bray anticline.

The only other evidence supporting the theory of a marine origin is the nature of the succession of platforms. The step-like pattern of platforms could be feasibly attributed to a river flowing parallel to the present coastline but there is no evidence that such a river ever existed. The pattern could not have been caused by the present drainage of the district.

Certain aspects of the platforms need further explanation. Compared with those of the Chalk areas of Southern England, they have a surprisingly large development. There is, however, a simple explanation of this. In most of the Chalk districts of England the platforms are cut solidly into the Chalk, whereas in France they have been cut largely into the basal Eocene and not deeply into the Chalk. Confirmation of this suggestion is provided by the large number of Eocene outliers and by the ubiquitous piping of the Chalk surface. Thus, the platforms are to be compared with the broad terraces of the Tertiary of the Hampshire Basin rather than with the narrow benches cut into such areas as the South Downs. The suggestion that the platforms were cut mainly in the Eocene would help to explain the gentle offshore gradients which must have existed during their formation. The modern offshore gradients in the Tertiary areas of Southern England are of the order of 10–15 ft. per mi., but the Chalk areas show offshore gradients of 40–50 ft. per mi. The gentler offshore gradients associated with areas of Tertiary rocks are probably due to the great amounts of sand and clay derived from the destruction of those rocks.

The almost complete degradation of the old cliff-lines is also difficult to explain but, if they were formed partly in the Eocene, they would not retain their steepness for as long as cliffs cut into Chalk. The explanation is, however, far from being completely satisfying. It can only be suggested that the deposition of the *limon* and periglacial action in the Pleistocene have contributed towards their degradation.

The platforms of the Dieppe region are, therefore, probably of marine origin. The landscape is similar in type but different in development from that of the Chalk areas of Southern England, as the platforms have resulted in a rough exhumation of the sub-Eocene surface. Depending upon the emphasis placed on the different aspects, one may regard it either as a platform-staircase or as an approximate exhumation of the sub-Eocene surface.

6. PLATFORMS IN THE WESTERN PART OF THE ENGLISH CHANNEL

Correlations of platforms by height alone has been condemned in the past but, when one is dealing with obvious platforms lacking any fossiliferous gravels, there is only one other criterion which can be used. It is the degree of development of the platform. Other things being equal, the longer stillstand will result in the wider platform. Further, some of the main platforms may be composed of a number of minor stages and, if similar composite platforms occur at the same elevations in different areas, they may probably be correlated. However inconclusive correlations based on height and degree of development may be, they are the only ones possible where palaeontological evidence is lacking.

Some major difficulties confront the correlation. Above the 650-ft. platform in Southern England lies the mid-Tertiary peneplain and something greatly resembling it is to be found in the highest platform of the Dieppe region. But, above a similar platform in South-west England, a number of fragmentary marine platforms have been found. Moreover, although Wooldridge (1929) demonstrated, by the deposits found thereon, that the 650-ft. bench in South-east England was of early Pliocene age, a different age has been assumed for the 180-m. platform of the Paris Basin. Baulig (1928 *a*, *b*) correlates 380-, 280- and 180-m. platforms in the Paris Basin with platforms at similar elevations in Bas Languedoc. These, in turn, are correlated with others near Algiers, where they truncate inclined Lower Pliocene strata. By these correlations Baulig argues that the 180-m. bench in the Paris Basin is of very late Pliocene age. A possible solution may lie in the suggestion recently made by Wooldridge (1950) that the 650-ft. platform in Southern England is also of the same age. There difficulties are all bound up with those of Pliocene stratigraphy and are really outside the scope of this paper.

The following comparisons of platforms are based upon a number of different types of investigations, the distribution of which is shown in Fig. 2: the late J. F. N. Green's field-studies of parts of Hampshire and Devon (Green, 1936, 1941, 1946, 1947, 1949), Baulig's statistical work on Brittany (Baulig 1928 *a*, *b*, 1935), studies of the Channel Islands (Mourant, 1933 and Hanson-Lowe, 1938) and the writer's own studies of the South Downs and the Weymouth district (1949, 1953). Most of these are field-studies made after the complexity of the platform-sequence had been realised, but Baulig's work is a statistical analysis of a great number of spot-heights made from a variety of French maps. Small discrepancies are to be expected from such factors as the variety of methods used, the position on the platform at which the elevations are taken, original differences in elevation due in part to differences in tidal range, and differences in the amount of subsequent dissection.

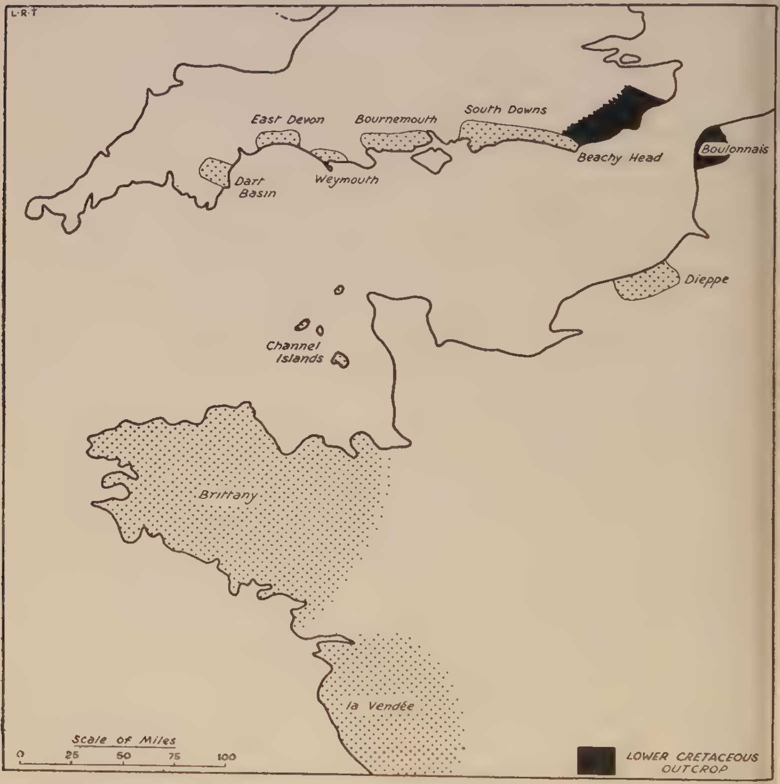

Fig. 2. Areas of detailed platform studies in the western part of the English Channel

For reasons outlined above, platforms above 700 ft. are not considered. Below this elevation the first platform is the Pliocene bench at *ca*. 650 ft. Wooldridge and Linton (1939) have traced it over large areas of the Chalk of Southern England, while Baulig described it as existing over much of the Paris Basin. As Baulig considered it to be a sub-aerial platform, he quoted the height of the forward edge of the bench. The elevation, therefore, is lower than that of the corresponding feature in England. In the vicinity of Dieppe the range of the platform is approximately 660–560 ft. Farther to the west the situation is more complicated. Baulig found the same platform in Brittany, but Green has two platforms, one at 690 ft. and the other at 595 ft. It may be that the platform in the east is double and that no one has yet succeded in separating the two minor stages satisfactorily, or there may be a genuine difference in the history of the two areas.

Below the 650-ft. platform comes the 530-ft. platform, which has, however, been noted only in a few areas. Green (1941) stated it to be strongly developed in East Devon and it is certainly found near Dieppe. There are certain features in the South Downs which might be regarded as belonging to this stage, but the evidence is too slight on its own. Further evidence for this platform is found in the 160-m. peak on the frequency curve of the Paris Basin and the 167-m. peak on the curve for la Vendée (Baulig, 1935).

Below this occurs a platform, generally not one of the most important ones, at 485–475 ft. The South Downs and Dieppe show the best development of the surface. It may be the same as Green's 505-ft. platform, which is not well developed and for which it is difficult to define the rear elevation (1941).

The 430-ft. platform is one of the most widely known in Southern England. It is found almost everywhere and rivals the 650-ft. in development. In South-east England the latter is the more fully developed; elsewhere, the former. On Baulig's curves it is represented by maxima at 128, 122 and 120 m. in different parts of Northern France, while a 400-ft. platform has been recognised in the Channel Islands (Mourant, 1933). The platform was one of the earliest to be recognised and took its place in the famous 600-, 400- and 200-ft. sequence. In addition, no one appears to have suggested that there were minor stages in the platform. Although it has never been dated conclusively, the presence of an easily recognised, widespread platform at the same elevation can hardly be due to mere coincidences.

The 380-ft. platform is definitely a minor one, as it appears to have only local developments. It certainly occurs in the South Downs, and there are probably traces of it in the Weymouth and Dieppe regions. Kirkaldy (Bull, 1942 in discussion) has observed it near Plymouth, while Green (1947) mentioned gravel, which he thought to be of marine origin, at Stoney Cross, Hampshire, at this elevation. In his last paper (1949), Green probably grouped this platform, which may well be the Poundsgate terrace of an earlier paper (1936), with the 430-ft. platform.

The 330-ft. group of platforms is widespread in distribution and not a simple terrace. In the South Downs an attempt was made to define its minor stages, but the subdivisions cannot be traced everywhere. They are of no great importance to the geomorphologist, as there were apparently no great physiographic changes within the period. Undoubtedly Green's Caton terrace (1936) and his Sicilian terrace (1946, 1949) belong here, although the Sicilian appears to vary in elevation and probably includes two different stages of this composite platform. In the Channel Islands, Hanson-Lowe (1938) derived former sea levels at 340 and 285 ft., the latter corresponding well with Mourant's 280-ft. platform (1933). Again, for Brittany and the Paris Basin, Baulig (1935) produced maxima of spot-height frequency at 104–105 m. and 86–93 m. Almost everywhere the platform is composite and thus satisfies one of the criteria for correlation.

Finally, the 230-ft. platform is composite, but has, apparently, a twofold division compared with the threefold division of the 330-ft. platform. The two divisions correspond with Green's Ambersham and Upper Ambersham terraces, the writer's 230- and 180-ft. platforms in the South Downs, 240- and 190-ft. platforms near Weymouth, and Hanson-Lowe's sea levels of 245–240 ft. and 205–195 ft. in the Channel Islands.

From the preceding discussion it can be seen that there is a general correspondence of the platforms round the western part of the English Channel in elevation, degree of development and degree of complexity. The areas studied are varied in structure and the platforms must be erosional surfaces. One may conclude that movements of base-level have probably been uniform, whether this be due to eustatic movements of sea level or to the uniform but irregular uplift of an area structurally diverse. Both mechanisms seem a little incredible, but the field-evidence strongly indicates the operation of one or the other of them.

If one assumes the 650-ft. platform to be Pliocene, it can be argued that the western part of the Channel has had its present form for a considerable period. The shape has not been always exactly the same, as, with a falling base-level, the area of the Channel has diminished slightly and former gulfs, such as the Hampshire Basin, have been abandoned by the sea. Further, the low glacial sea levels of the Pleistocene must have caused a large emergence of the sea-floor. But the general conclusion that the western part of the English Channel has not altered much for a long period, remains true. At the 650-ft. level, Wooldridge & Linton (1939) show a complete channel between the Pliocene land-masses of the Weald and France, as the North Downs, South Downs and Boulonnais Chalk were all obviously bevelled. After that stage one cannot be sure of what happened to the central part of the Channel. All shorelines below 500 ft. turn out to sea at Beachy Head and the same is probably true of the other areas. In the areas of Lower Cretaceous rocks exposed within the Weald and Boulonnais the platforms do not appear to have been traced. Further, the strange courses of the Rivers Stour and Cuckmere (Davis, 1895) indicate that the present shoreline is one of recent origin. Thus, at present, nothing can be said about that part of the English Channel within the Weald and Boulonnais. That part of the Channel, which lies west of Beachy Head in England and west of the southern rim of the Boulonnais in France, is evidently an old feature.

ACKNOWLEDGMENT

I wish to express my thanks to the University of London for a grant from the Central Research Fund to cover the expenses of this investigation.

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MULLION AND RODDING STRUCTURES IN THE MOINE SERIES OF SCOTLAND

By Gilbert Wilson, Ph.D., F.G.S.

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ABSTRACT.—Distinction is drawn between *mullions* which look like 'clustered columns' and are composed of the local country-rock, and *rodding* which consists of quartz-rods derived from silica secreted from the rocks during movement and metamorphism. The mullions of Oykell Bridge in South Sutherland are described, and are found to consist of varieties formed by folded bedding, intersecting bedding and cleavage, and of irregular types. Their elongation plunges to the south-east and is parallel to the local fold-axes. The quartz-rods of Ben Hutig in North Sutherland (*Beinn Thutaig* in the NW. Highland Memoir, pp. 601–3) plunge gently to the east and are parallel to the axes of recumbent folds seen between Ben Hutig and the Kyle of Tongue. The rods have been formed by rolling or shearing movements acting at right-angles to their lengths. Neither the quartz-rods, nor the mullions, nor the folds with which they are associated, seem to bear any relationship to the Caledonian thrust-movements. The structural evidence supports Horne's, Read's and Coles Phillips' views that the age and folding of the Moine Series was pre-Torridonian.

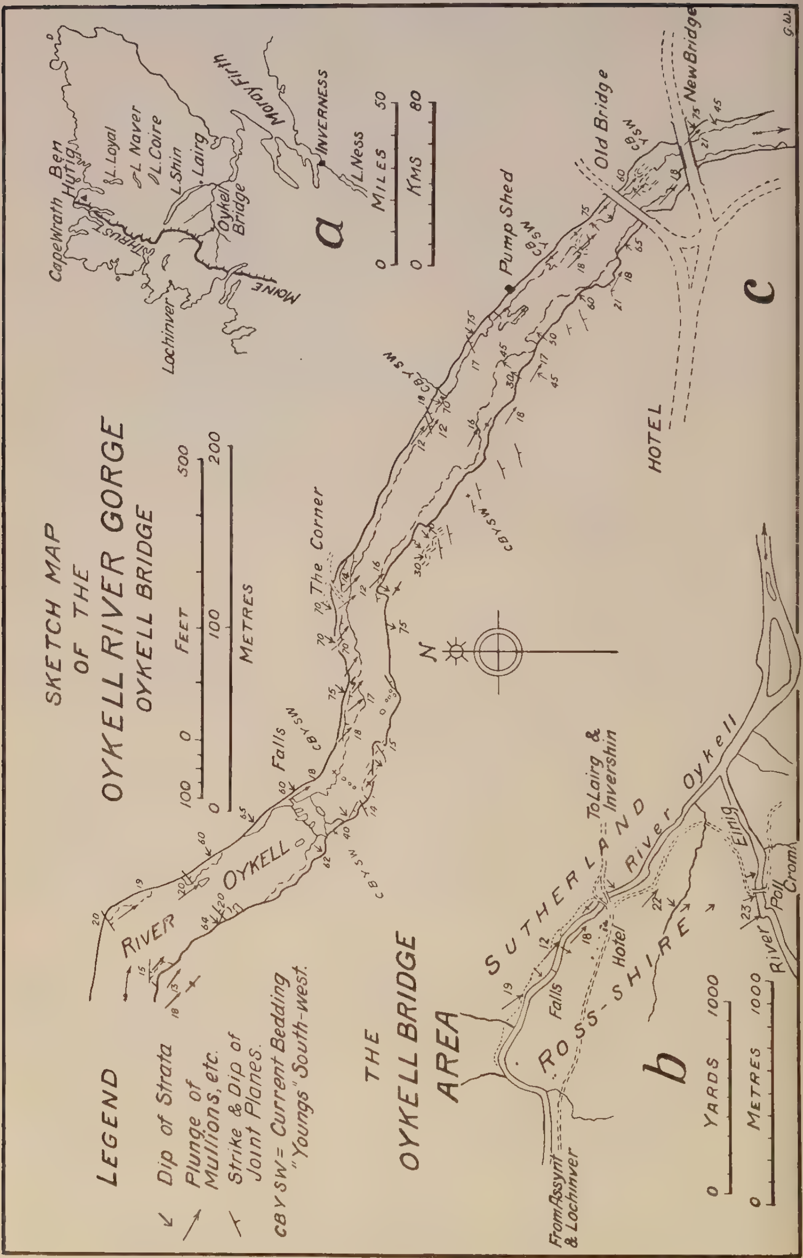
1. INTRODUCTION

IT is surprising that, though tectonic interpretations of mullion and rodding structures have been made in various publications, there is no general description of actual field occurrences giving details of what these structures look like, nor is there any adequate discussion of their genesis. In order to fill these gaps, I visited Oykell Bridge on the Sutherland–Ross-shire boundary, and Ben Hutig in North Sutherland, two of the classic areas where these phenomena are displayed (Fig. 1 *a*) and the following gives an account of my observations and of the deductions based on them.

The terms 'mullion' and 'rodding' have been used more or less synonymously in the past, but in this paper I have distinguished between the two. They were grouped together in the North-West Highland Memoir (Peach & Horne, 1907), by the unsatisfactory term of 'Linear Foliation'. Read (Read & Phemister, 1926) used both terms in discussing the Oykell Bridge mullions. Holmes (1928, p. 163) stated that mullion structure recalled 'the appearance of the clustered columns which support the arches, or divide the lights of mullioned windows, in Gothic churches. The structure is also described as *Rodding Structure*, and is typically developed in the Eirebol district, where "rods" of white quartz, varying in dimensions from those of telegraph poles to those of walking sticks, lie parallel to each other down the dip slope of the Moine schists. Where minerals of elongated habit like hornblende and biotite are present in the rocks showing mullion or rodding structure the crystals are arranged parallel to each other and to the dip and pitch of the folds.' Holmes, too, compared it with linear foliation. His description is apt, and in its concise form could not be bettered. He also noted that the term was in use in 1891 by workers in Donegal, where it was probably coined originally. Though E. Hull, G. H. Kinahan, J. Nolan, *et al.* (1891) refer to mullion structures in that area, no early description of them has been found. I am indebted to Drs. W. S. Pitcher and G. J. H. McCall for specimens and notes from that very district. There is a marked similarity in the appearance and mode of occurrence of the mullions in Donegal to those found in the banks of the Oykell River. Bailey and McCallien (1937, p. 103) suggested the use of the term '*corduroy structure* to include what some have called mullion structure in . . . the North-West Highlands'. Fermor (1909, p. 935; and in McIntyre, 1952, p. 17) had applied the term *slickensides-grooving* to structures that he described as 'parallel striated and grooved prisms suggesting logs of wood'. This description could equally well be used for some of the Scottish mullions. In 1924, Fermor also discussed the parallelism of such coarse lineation with the plunge of local fold-axes, and he pointed out that it should be mapped and used to elucidate fold-structures in ancient metamorphic rocks.

The main distinction between mullion structure and rodding, as used in this paper, is that mullions are formed of the normal country-rock, while rodding is developed from quartz that has been introduced into, or has segregated in, the rocks. Isolated quartz-rods can be observed in many parts of Sutherland, where they lie parallel to the local fold-axes and corrugations of the Moine Schists. The best examples occur at the summit and on the eastern slopes of Ben Hutig on A'Mhoine—the type area of the Moine Series—and are mentioned by Peach & Horne (1907, pp. 601–3).

The investigation of the Oykell Bridge mullions was undertaken at the


SKETCH MAP OF THE
OYKELL RIVER GORGE
OYKELL BRIDGE
FEET
100
0
100
500
METRES
0
100
200
LEGEND
Dip of Strata
Plunge of Mullions, etc.
Strike & Dip of Joint Planes.
CBYSW = Current Bedding "Youngs" South-west.
THE OYKELL BRIDGE AREA
RIVER OYKELL
Falls
The Corner
Pump Shed
Old Bridge
New Bridge
HOTEL
N
CBYSW
a
Cape Wrath
Ben Hutig
L. Loyal
L. Naver
L. Coire
L. Shin
Lairg
Oykell Bridge
Moray Firth
Inverness
L. Ness
Lochinver
Moine
Thrust
Miles 0 50
Kms 0 80
b
SUTHERLAND
ROSS-SHIRE
River Oykell
To Lairg & Invershin
Hotel
Falls
From Assynt & Lochinver
Einig
River
Poll
Cromh
Yards 0 1000
Metres 0 1000
c
G.W.

suggestion of Professor H. H. Read, F.R.S., who also has been responsible for many helpful criticisms of the manuscript. The expenses incurred in the field-work on Ben Hutig were defrayed by a grant from the Central Research Fund of the University of London, which is gratefully acknowledged.

2. THE MULLIONS OF OYKELL BRIDGE

(a) **General Considerations.** Mullion structure is mentioned in few text-books. In the United States of America it was considered that 'where the movement [on a fault] has been considerable there may be large grooves or furrows on the fault walls, sometimes called *mullion structures*. This structure indicates the direction of the displacement. The grooves may be several feet from crest to crest. Fine examples of these structures may be seen in the Highlands of Scotland . . . and perhaps in the Rodadero fault of Cazcol, Peru' (Leith, 1923, p. 100; see also Gregory, 1914). Billings (1942) agreed with Leith. Fairbairn (1949, p. 178) followed the same line of thought when he stated: 'The rodding and mullion structures of thrust fault zones, with the thrust direction parallel to the rod axes, may or may not be flexure folds.'

The Strath Oykell Memoir (Sheet 102), in which the area under consideration was described, contained a brief discussion by Read on the origin of the mullion structure (Read & Phemister, 1926, p. 121): 'The rodding [mullion structure] is the result of two systems of folding. There is first a folding produced by compressive forces acting in a north-east and south-west direction, and second a deformation, at right angles to this, resulting in a stretching along north-west and south-east lines and with axial planes dipping south-east. The stretching is in harmony with the Moine Thrust . . . and may be regarded as an obvious accompaniment of the thrust movement towards the north-west.' These conclusions were supported by Coles Phillips (1937, p. 597), where he demonstrated that the structural *b*-axis was parallel to the lengths of the mullions, and considered that 'the small amount of folding present [in the particular example that he discusses] is of the nature of flexure folding, but the outline of the surface of the mullion is independent of the foliation and in no way determined by the folding. . . . It is the lineation parallel to the *b*-axis of the fabric which has provided the direction of yield during the later thrust-movements.' Detailed examination of the mullions at Oykell Bridge has confirmed these statements, but the evidence also indicates that the north-east–south-west folding-movements were of far greater importance than any thrust-movements which acted towards the north-west.

(b) **Geological Setting.** Oykell Bridge is on the road from Lairg and Invershin to Loch Assynt (Fig. 1 *b* and *c*) and for many decades has been crossed by geologists hastening to the classic Inchnadamph area. The outcrop of the Moine Thrust lies about 6½ miles to the west. The bridges—there are now two—cross the Oykell River where it pours through a narrow rock-sided gorge, on the walls of which the mullion structures form a coarse ribbing that plunges downstream at about 18° to the south-east (Plate 7A). Exposures are good on both sides of the gorge as far upstream as Oykell Falls, above which the river flows between low banks. Bedrock in the banks continues to crop out for a further distance of about 150 yds., but beyond this point the river meanders down a valley floored by drift and alluvium. Downstream below the bridges are a few exposures which in a short distance yield place to glacial drift. The Oykell River is joined by the Einig, a tributary flowing from the west-south-west, about half a mile below the bridges. Good rock-exposures crop out in the bed of this stream, particularly at Poll Cròm, near a wooden bridge which lies due south of Oykell Bridge and the Hotel (Fig. 1 *b*).

The Moine Series in this area consists dominantly of light grey, siliceous granulites in which the original bedding lamination shows as fine dark bands. Thin semi-pelitic, and rarer pelitic layers occur in the granulites of the gorge, and more micaceous varieties are found locally farther to the west. Current-bedding is not uncommon in the Moinian rocks hereabouts, and all occurrences seen in the Oykell Gorge and to the north-west clearly indicate that the tops of the beds face south-westwards.

The gentle south-south-easterly dip of the beds seen at Poll Cròm continues northwards as far as a small stream midway between the Einig and the Hotel (Fig. 1 *b*). At this locality the rocks are contorted and a sudden change in their orientation occurs; the strike becomes north-westerly, and the dip is 55° to the south-west. This direction of strike is the same as that in the Oykell gorge, but the dip there is more variable and near the bridges the beds are locally overturned. In places the folding in these steeply-inclined beds actually becomes isoclinal. In general, however, the structure is simple, and consists of a large **L**- or **Z**-shaped fold whose axis plunges to the south-east. The gorge of the Oykell River follows the beds on the steep north-easterly limb of this fold, a little to the north-east of the turn-over. The rocks of the Einig represent the flat limb of the **L** or the base of the **Z**. The current-bedding observations indicate that the structure is synclinal closing to the north-east. The spectacular mullions in this area thus lie in or near the core of this syncline, and are considered to be the result of the crumpling and rupture of the beds in the heart of the fold: they are accommodation-structures.

The mullions are excellently exposed in side view on the walls of the Oykell Gorge, and true profiles of the structures can be seen on numerous cross-joint surfaces. Three main varieties of mullions are recognised:

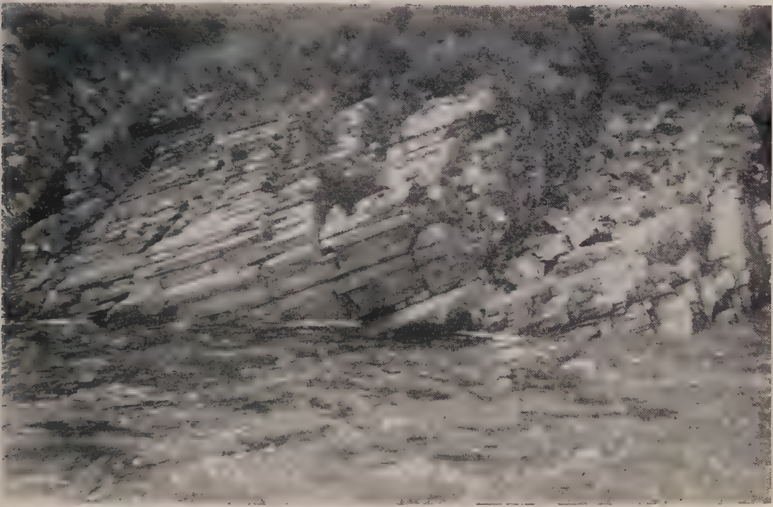
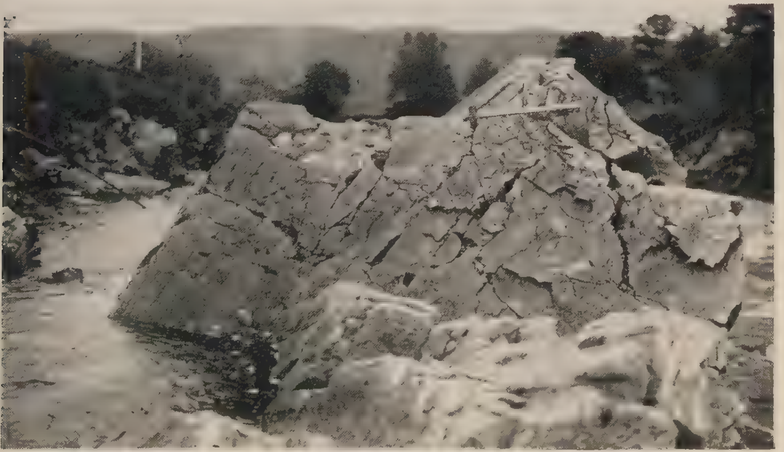


Photo by P. G. Cooray, 1951

A.—Mullion structure with cross-joints; Ross-shire bank of the River Oykell between the bridges



B.—End view of irregular mullions, looking down the plunge, River Oykell

1. Bedding- or fold-mullions.
2. Cleavage-mullions.
3. Irregular mullions.

(c) **Bedding- or Fold-Mullions.** Bedding- or fold-mullions are formed by the parting of the rock along cylindroidal undulations or flexures of the bedding which in the larger examples have radii of curvature of up to 3 ft. (1 m.). Bedding-lamination shows up well in these structures, and is conformable with the mullion-surfaces. The mullions are not complete cylinders, but are undulations of half-round, quarter-round, or of even lesser arc, and the coarse lineation-effect is produced by convex surfaces alternating with concave. The larger mullions are composed of more massive, competent beds than are the smaller. Such beds have resisted the movements and have not crumpled to the same extent as the less competent strata, but, locally, tightly-folded beds have broken and are pushed over the thin-bedded granulites along minor shear-planes. Some of these planes are themselves crumpled so that the surfaces of discontinuity—the mullion surfaces—cut across folded bedding-laminations in one place and follow it in others. A fold-mullion may thus be bounded by a curved cylindrical surface as one part of its periphery, while the remainder is made up of concave or convex parallel or grooved surfaces which cut across the internal rock-structure. Fold- or bedding-mullions between the two bridges are illustrated in Figs. 2 and 3. The structures all show the same style and all have the same plunge of about 18° towards south 30° to 35° east.

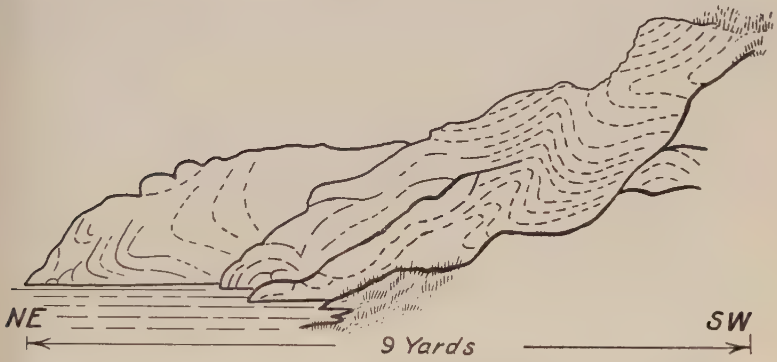


Fig. 2. Profiles of fold-structures, looking down the plunge, on the Ross-shire bank of the Oykell River, between the bridges

Fold-structures, which yield or might yield mullions in longitudinal exposure, are not confined to this short stretch of river-bank. Similar occurrences can also be seen across the river, and a well-exposed fold lies below the Old Bridge on the Sutherland side. The outer beds of the fold are composed of evenly-bedded granulites, the core is of more massive rock. The thinner, outer beds are dragged and ribbed and locally broken by shearing; the bedding-laminae of the more massive core show crumpling which is obviously the result of accommodation to the abrupt turnover of the fold. Further folding can be observed in various exposures on the Sutherland bank as far upstream as the 'Pump Shed'. They all show the same general fold-style of **L**-shaped folds plunging down the line of the river at approximately 18°.

Recumbent folding, which plunges S.50°E. at 22°, shows in a rock-face 300 yds. south of the New Bridge beside the track leading to Poll Cròm. Two isoclinal folds, one lying above the other, have been etched out by weathering on a cross-joint face (Fig. 3 *a*). The fold-surfaces show striations parallel to the plunge, and the smooth top of the exposure, which is parallel to the axial planes of the fold, is similarly lineated.

A remarkable lone mullion resulting from erosion of an abrupt double fold is found at Poll Cròm. The anticlinal crest of this fold, forming an almost complete half-cylinder, emerges from below the drift on the north bank of the stream, and plunges at 23° towards S.35°E. into the waters of the river. When seen from a distance, it appears to be nothing more than a partly submerged fallen tree-trunk. The asymmetry of the fold indicates that it was formed by an over-thrusting movement towards the west-south-west.

The details of two small fold-mullions, now in the Imperial College collection, are shown in Fig. 3 *b* and *c*. The thin laminae *within the mullions* are smoothly bent into similar folds, and the outer mullion-surface is covered with a thin micaceous veneer which is conformable with the core. This micaceous veneer was formed at a later date than the folding of the rocks, as shown by the fact that the skin is continuous around the mullion. In one place it is conformable with the internal structure, but elsewhere it is cross-cutting. This can be seen by comparing the upper and lower portions of the two mullions sketched in Fig. 3 *b* and *c*. The effect of this micaceous skin is to form a discontinuity between the mullion and the surrounding host-rock; hence the external structure of the rock, in which the mullion lies, abuts against the smooth surface. As weathering proceeds, the surrounding rock falls away and an inclined cylindrical column of rock partly embedded in the walls of the gorge is thus exposed. Fold-mullions present every gradation from corrugated bedding-planes, through crests of drag-folds or of tight isoclinal folds formed from a continuous bed, to the separated, pinched-off crests of small isolated folds (Fig. 3 *b*).

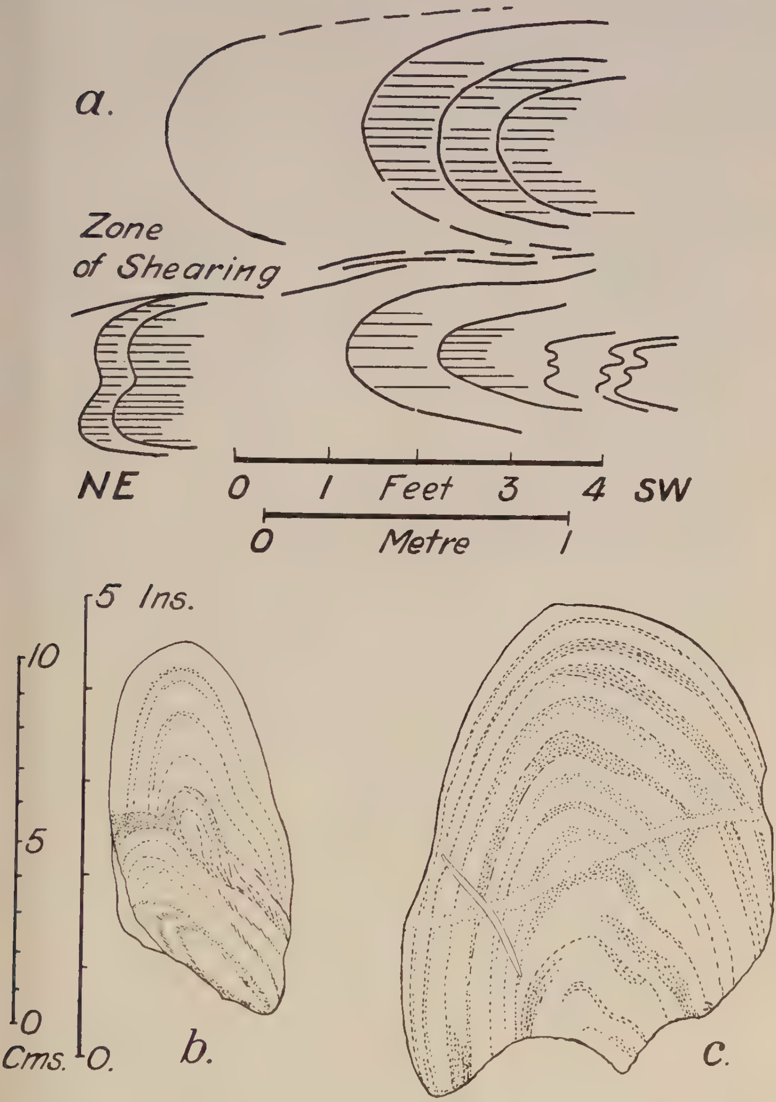


Fig. 3 *a*. Profiles of recumbent folds 300 yds. south of the New Bridge.
b and *c*. Profiles of fold-mullions showing the concordant and discordant structure of the mullion periphery

(d) **Cleavage-Mullions.** Cleavage-mullions are long rock-prisms which may be angular, sub-angular, or roughly rounded in section. This they owe to fracture along intersecting cleavage- and bedding-planes. In the loose they form elongated blocks having rhombic cross-sections bounded at the ends by cross-joints. An excellent example, at least 9 ft. long, stands as a monolith in the Hotel grounds.

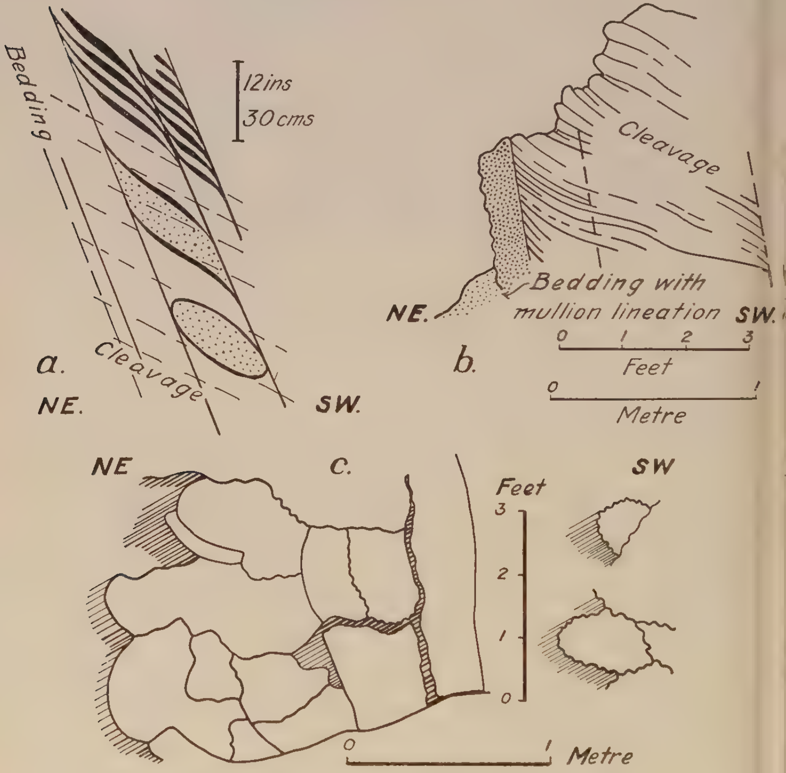


Fig. 4 *a* and *b*. The development of and examples of cleavage-mullions. *c*. Profiles of irregular mullions

An easily visited exposure, showing the development of this class of mullion, lies in the Sutherland bank of the river downstream from the New Bridge. The beds here dip 75° towards S.45°W., and are 1½ in. to 6 in. (3 to 15 cms.) or more in thickness. The bedding-planes are striated by a fine lineation which plunges accordantly with the other structures to the south-east. The contacts between thin beds and more massive ones are corrugated by small asymmetrical rolls which were produced by a down-dip slip. Semi-pelitic layers between massive siliceous granulites are crumpled and squeezed out; and undulations of the strata yield large-radii fold-mullions. The dip of the cleavage is flatter than that of the bedding and is inclined towards the south-west at angles varying from 30° to 45° (Fig. 4 *a*). It originally formed smooth planes or sigmoidally curved surfaces. Locally movement on these surfaces has ground the edges of the rhombic-shaped blocks between the fracture-planes, rounded their corners, and so converted them into cylinders of more or less oval cross-section. These, like other mullions, are covered with a thin micaceous veneer. Elsewhere the ribbed or coarsely lineated surfaces of some exposures (Fig. 4 *b*) have been produced by differential weathering of exposed edges of the cleavage-flakes.

Cleavage becomes more important from a morphological point of view as one approaches the Oykell Falls, particularly on the Sutherland bank. The rocks, which crop out from 'The Corner', up to and beyond the Falls, have broken away along planes of bedding and of cleavage, which latter curves downwards towards the south-west. The dip of the beds over this stretch is between 60° and 70° to the south-west. The cleavage has variable dips in the same direction but is everywhere flatter than the bedding. Small drag-folds in pelitic or semi-pelitic intercalations also reflect down-dip movements. (It should not be forgotten, however, that current bedding shows that these strata are still right way up.)

Because of the intersection of cleavage and bedding the rocky wall of the gorge near the Falls is eroded into a series of obtuse-angled steps, the upper surfaces of which slope outwards and are partly rounded. The ledges thus formed pitch down the walls of the gorge—especially beside the Falls—in conformity with the plunge of the other mullions.

(e) **Irregular Mullions.** The irregular mullions are the most baffling of the various types observed. They are long cylindroidal masses of rock of very irregular cross-section. The irregularities vary from fine striations to grooves comparable with corrugated-iron sheeting: the larger corrugations are themselves striated by finer parallel grooving. Sketches of irregular mullion-profiles are shown in Fig. 4, *c*, and other examples are illustrated in Plate 7B. The curved surfaces of these mullions, on one side or another, may be controlled by contorted bedding, but on the whole there is little relationship between external form and bedding-lamination. The internal micaceous laminae are indiscriminately truncated by the corrugated surface of the mullions as noted by Phillips (1937, fig. 6, p. 596). These mullions, like the other types described above, are coated by a thin micaceous veneer and, as they weather, they break away along these surfaces. Their edges fit together like pieces of a jig-saw puzzle, or the teeth of a cog-wheel; but internally they are, except for bedding-laminations, hard, compact and homogeneous.

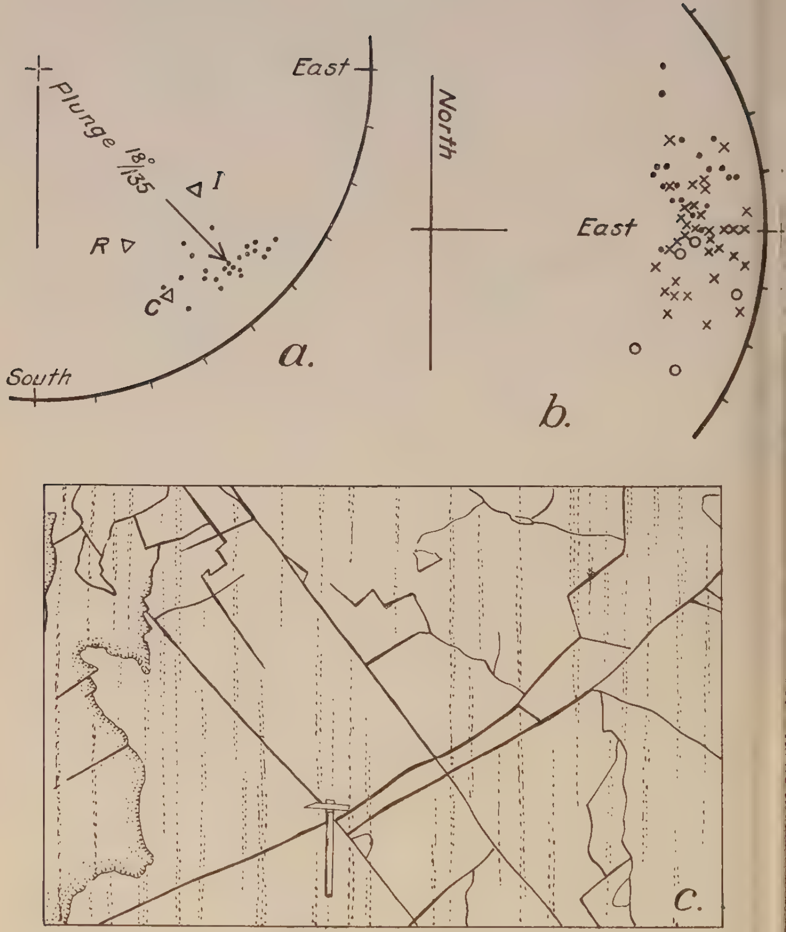


Fig. 5 *a*. Point diagram showing the projection of mullion axes, etc., around Oykell Bridge, on an equal-area projection, on the lower hemisphere.
I = Invershin; R = Rosehill; C = Exposure near Loch Craggie.
b. Point diagram showing the projection of quartz-rods on Ben Hutig (dots); fold axes and linear structures—*B*-axes—between Ben Hutig and Melness (crosses); near-by *B*-axes from Coles Phillips, 1937, pp. 608–9 (circles).
c. Plan view of jointing and lineation in gently dipping beds at Poll Cròm.

Similar mullions from Donegal, composed of massive felspathic quartzite or highly siliceous granulite, are even more fantastically shaped than those from the Oykell. They have the same cylindroidal forms which may or may not be controlled by bedding-lamination; many are bounded by plane-surfaces, and are cleavage-mullions. They commonly weather out as columns long and big enough to use as gate- or fence-posts.[1]

It is noteworthy to remark that, despite the strong development of mullions around Oykell Bridge, where the beds dip steeply, they are absent on the River Einig, with the exception of the one fold-mullion already described. The stratification on the Einig dips about 25° south-south-easterly and shows a fine corrugation roughly parallel to the dip on exposed surfaces; in places this grades to a gentle undulation. When the beds are viewed in strike-section, for example at the bridge near Poll Cròm, it is seen that individual beds are not continuous: they 'pinch and swell'. The structure is rather suggestive of embryonic boudinage developed by tension or drag acting normal to the direction of lineation, which plunges gently towards S.30°E.

(f) **The Orientation and Symmetry of the Mullions.** The mullion- and lineation-structures in the Oykell Bridge area are homoaxial and plunge south-eastwards. The observations of plunge have been plotted as a point-diagram on the lower hemisphere of an equal-area projection (Fig. 5 *a*) and the concentration of poles is remarkable.

Dr. D. B. McIntyre, who visited the area while I was at work on it, informed me that 5½ miles to the east in a road-side quarry near Rosehall, the lineation plunged S.27°E. at 40°, and at Invershin it was S.52°E. at 42°. These two readings are also shown on the diagram.

Individual mullions show a remarkable constancy along their lengths. They are cylindroidal in form and have monoclinic symmetry with a plane of megascopic symmetry normal to the direction of plunge; the lengths of the mullions are parallel to the *B* structural axis (Sander, 1948, p. 132).

The larger-scale folding, wherever the pattern can be clearly made out, presents the same class of symmetry as the mullions, and its plunge is accordant with that of the observed corrugations. This is not only true for the structures in the Oykell gorge, but also for similar features seen along the road to the west. A road-side outcrop, four miles from Oykell Bridge, just south of Loch Craggie, has the same structural style as that observed in the area under discussion (Plate 8A). The fold plunges at 21° towards S.30°E., and minor corrugations in semi-pelitic beds reflect the larger structure. Other folds in the same area show similar features, and exposures near the road between this locality and Oykell Bridge all tell the same story. The megascopic symmetry is monoclinic, and the plunge of the fold-axes and of lineation is south-eastwards. The general dip of the beds, seen in scattered exposures, is towards the south-west, and the orientation of drag-folds indicates that the upper beds moved down-dip or south-westwards relative to the lower. On one exposure on the road, current-bedding shows that the top of the beds also faces south-west.

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[1] Personal communication from Drs. W. S. Pitcher and G. J. H. McCall.

Cross-jointing, which has already been referred to, forms a prominent structural feature in the Oykell Gorge (see Plate 7A). The majority of the planes are normal to the plunge of the mullions, but exceptions, which are roughly vertical or slightly oblique, occur in several places. Oblique joints, which are symmetrically oriented on either side of the lineation, are well seen on the bedding-surfaces at Poll Cròm (Fig. 5 *c*). It is significant that the two joint-sets form angles of about 50° with the linear structures: the bisector of the acute angle between the joints, which is commonly parallel to the direction of movement or of applied compression, is normal to the lineation (Wilson, 1946, p. 284; 1952*a*, pp. 26–7).

Other joints do not fit the pattern of monoclinic symmetry. Many can be observed dipping gently south to south-eastwards, particularly along the Ross-shire bank of the river. They seem to be associated with a rolling shear-plane which occurs at 'The Corner' on the Sutherland side, some 300 yds. upstream from the bridges. This fracture dips gently to the south and then swings so that its inclination becomes south-westwards and thus coincides with that of the local bedding-planes.

One very local set of joints cuts a group of steeply-dipping beds immediately upstream from the Old Bridge. In plan these joints appear as closely-spaced cross-joints, but in side view they can be seen to dip at 70° to 80° downstream, and so form a coarse fracture-cleavage, such as might have been generated by a shearing movement acting up the plunge of the structures. These joints present the only megascopic evidence seen in the Oykell Bridge area that the rocks hereabouts may have suffered any thrusting from the south-east.

From the field-evidence described in the pages above it appears that the mullion structures seen in the Oykell Bridge area are structures of Sander's *B*-axis type (Sander, 1948, figs. 44, 45), and that they have been formed by tectonic movements acting normal to their elongation. The asymmetry of the local folding, the orientation of the cleavage and its relationship to the bedding, indicate that the sense of the translation was from north-east towards the south-west. Movements towards the north-west along the length of the mullions—that is, roughly in the Caledonian direction—may have affected the structures, but only in a minor, superficial manner, and at a later period than that of the original formation of the mullions.

3. THE QUARTZ-RODS OF BEN HUTIG

(a) **Geological Setting.** Ben Hutig in North Sutherland (*Beinn Thutaig* on Sheet 114, in Peach & Horne, 1907, and in earlier papers) forms the back-bone of the rectangular promontory of A'Mhoine—the type-area of the Moine Series (Fig. 6).

The promontory is bounded on the west by the mouth of Loch Eriboll, by Loch Hope and the Hope River; its eastern edge is the shore of the Kyle of Tongue; and the north coast consists mainly of inaccessible precipitous cliffs. The greater part of the area is a desolate peat-covered plateau, which accounts for its Gaelic name, A'Mhoine—the peat-moss. From it Ben Hutig (1340 ft. or 412 m.) rises as a north-north-easterly trending escarpment. The undulating and gently-sloping east flank of this mountain drops to sea level in Strath Melness, roughly two miles (3.3 km.) from the summit-ridge. The steep scarp faces west and falls by precipice and drift-covered slopes over 400 ft. (125 m.) in a horizontal distance of about 400 yds. (375 m.). At its foot lie the most easterly thrusts of the Moine Thrust zone; they control the trend of the scarp and are marked by two narrow depressions separated by a ridge composed of Lewisian Gneiss. Immediately to the west of these fault-line features are exposures of 'frilled schist'—sheared phyllitic rocks—and a mile and a half (2400 m.) still farther west is the Moine Thrust itself (Peach & Horne, 1907, p. 487, fig. 23). This last dislocation 'is not the true continuation of the Moine Thrust of Assynt, but an intermediate thrust in advance of the main thrust-plane, which is presumably, as elsewhere, that bounding the Moines and passing over the coarse gneiss' (Green, 1935, p. lxxvi). I agree with this suggestion that the thrust at the foot of the Ben Hutig scarp-face is really the true Moine Thrust. It is to the east of this line that rocks of the Moine Series first crop out, and Ben Hutig as well as the surrounding plateau to the south and east are composed of typical siliceous and semipelitic Moine granulites, with less common layers of inter-bedded pelitic garnet-mica-schist, Durcha-type hornblendic granulites and garnetiferous amphibolites.

The 'dip-slope' of the Ben Hutig escarpment is controlled by a combination of bedding-surfaces and planes of cleavage or schistosity. Over large areas these two planes of parting more or less coincide; but locally, where the bedding becomes steep or contorted and the strike swings around folds until it is east–west, the secondary structural planes, which are parallel to the axial planes of the folds in the granulites, control the general slope of the topographic surface. Similar control of topography by cleavage has been recognised by Fourmarier (1948). All the folds that I have mapped so far plunge eastwards, almost directly down the dip of the cleavage-planes, and, as can be clearly seen on cross-joint surfaces, they

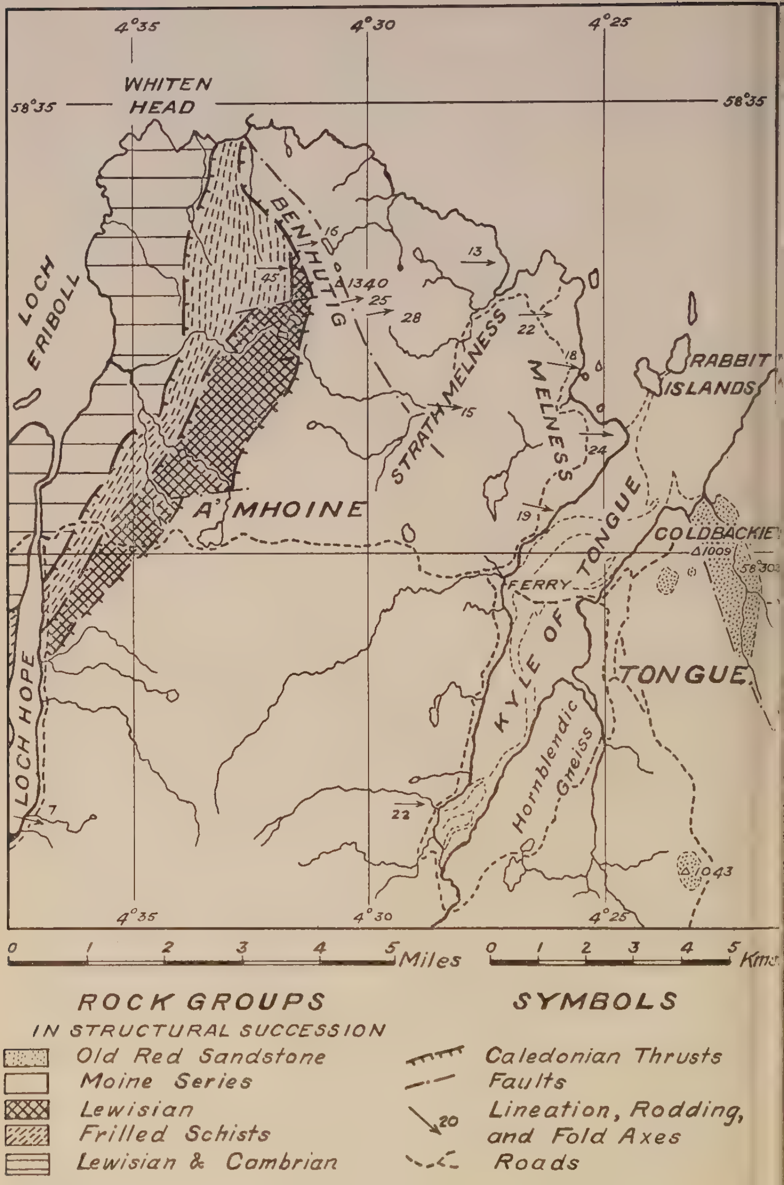


Fig. 6. Geological sketch-map of A'Mhoine. (After G.S. Sheet 114.)

are in section flat recumbent isoclinal flexures which locally grade into shear-folds. The majority are overturned from the north towards the south. A few are overturned in the opposite sense.

The connection between east-plunging folds and the quartz-rods was recognised by Peach & Horne who stated (1907, p. 603) ' . . . in the midst of the granulitic series frequent examples appear of folding along axes that trend WNW. and ESE. The most striking instance of this structure is to be seen on the south-east slope of Beinn Thutaig [Ben Hutig] about three-quarters of a mile from the top of the hill. Here . . . a series of rods, varying from two to four feet in length and from one to four inches in diameter, are composed of irregular grains of quartz with some flakes of white mica. These rods are associated with mica-schists of Moine type, which have been thrown into sharp anticlines and synclines, with axes trending like the rods towards W.12°N, and with a pitch towards the east [S.78°E.]. On exposed surfaces where the mica-schist has been denuded into hollows, these siliceous ribs project and form conspicuous features in the landscape.' These rodded structures continue in scattered exposures up to the summit ridge of Ben Hutig, where every stage in their development can be observed.

(b) **The Formation of the Quartz-Rods.** Little time is needed on the summit-ridge of Ben Hutig for one to realise that there is every gradation between plane or flatly lenticular quartz-veinlets on the one hand, and cylindroidal quartz-rods on the other. Both are the products of quartz-segregations which were formed during the folding, shearing and metamorphism of the country-rocks. Some veins are undistorted and clean-cut, these must have been formed at the end of the period of movement. Others that formed during the movements were distorted, folded, or even rolled to varying degrees, and are now seen as rods. The original quartz-segregations developed along three main planes of weakness in the rocks, and can be locally subdivided into (i) those which lie along planes of secondary cleavage or foliation; (ii) those whose formation was controlled by original bedding, and (iii) those which filled fissures oblique to these two important structural surfaces.

Segregation-veins, which developed along the secondary, axial-plane foliation of the country-rocks, are parallel to the bedding on the flanks of the isoclinal folds, but they naturally cut the stratification at the fold-nose where the bedding curves over (Fig. 7).

In flexures that have changed to shear-folds, the quartz-lenses lying along the planes of movement have been broken and rucked by the slip on the foliation with the production of small quartz-rods which show crescentic cross-sections. The rods lie in the general plane of the foliation, and their elongation is parallel to the plunge of the folds.

Veins, which formed parallel to the bedding planes of the country-rocks, have been folded with the stratification (Fig. 8 *a* and *b*). Other segregations, which developed during the folding, tended to become concentrated in the reduced-pressure zones of fold-apices. As folding continued the segregations were rolled by the movement, and any veinlets connecting them along the bedding with neighbouring quartz-masses were stretched or broken. The resultant quartz-bodies are now more or less isolated, irregular cylindroidal rods varying from half an inch (1 cm.) to over 2 ft. (60 cms.) across (Fig. 8 *c* and *d*). The plunge of each example illustrated is 'into the page', i.e. eastwards.

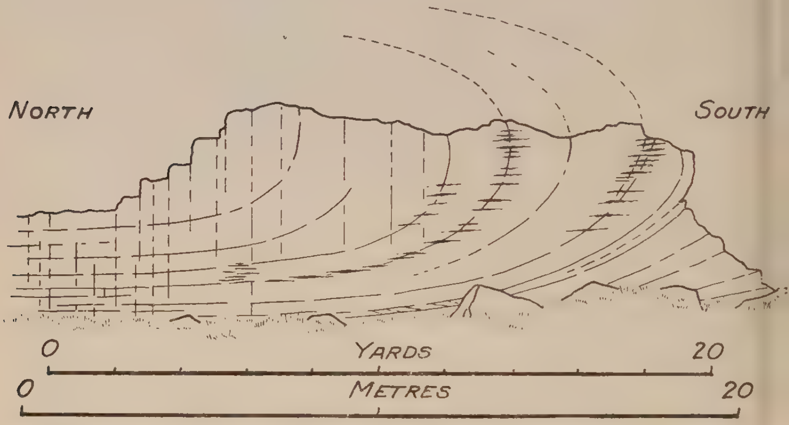


Fig. 7. Recumbent fold near Melness, showing the development of quartz-veins along the axial-plane cleavage

Each of the four sketches in Fig. 8 represents a different stage in the evolution of the rods; as deformation continued the product became more and more linear. This was the result of either the rolling of the segregation in the fold-apex, or of the breaking up of the quartz-veinlets into rods by attenuation along the stretched limbs of minor corrugations. Nowadays, as the rocks weather away, the fold-crests of resistant quartz separated by more easily eroded strips of country-rock stand out on the dip-slopes as a coarse lineation, which is parallel to the plunge of the folding.

Other rods have developed from quartz-filled gashes which originally lay at an angle to the planes of bedding or foliation. Undeformed fractures of this class occur *en échelon* in zones traversing the country-rocks, and have been formed by the slip of the Moinian rocks towards the south-south-west and the south (Wilson, 1952*b*). Those gashes and veinlets, which are still well preserved, must have been formed at the end of the period of movement; but others, which developed earlier in the tectonic episode, have been twisted and sheared in the deformation (Fig. 9 *a*). Three stages in the evolution of rods from quartz-filled tension-fractures are shown in Fig. 9 *b*. Where the rods have been involved in prolonged movement they may attain an oval or nearly circular cross-section, and lie in recrystallised semi-pelitic granulites from which primary structures such as bedding have been sheared out. In these circumstances one cannot decide on the original forms of the segregations that have been so moulded by the movement.

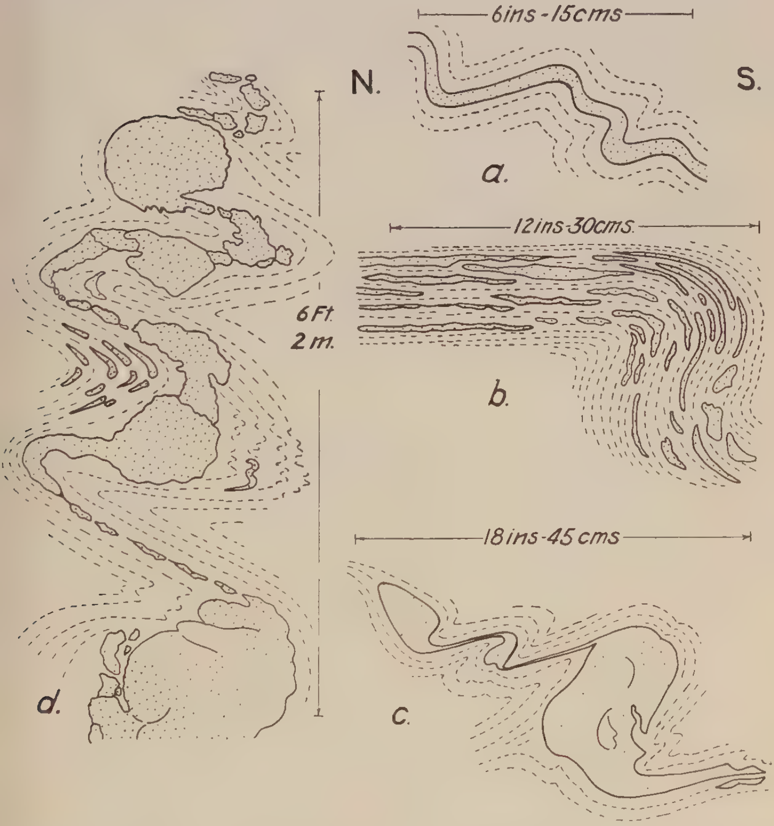


Fig. 8 *a*. Slightly folded quartz-vein parallel to the bedding.
b. Stretched and folded quartz-lenses parallel to the bedding.
c and *d*. Profiles of quartz-rods developed in the apices of small-scale folds. All seen near the summit of Ben Hutig.

(c) The Influence of the Country-Rocks on the Development of the Quartz-Rods. The rods of Ben Hutig are not ubiquitous. A dip-surface may be found to be covered with typical stick-like rods, but if it is viewed end on, or in side-section, it is often seen that the rods are confined to a particular stratum or to a zone in the rocks. Rods occur in profusion in some beds, and rarely or not at all in others. One can see such beds interstratified with each other—plain and rodded. The plain, unrodded beds are for the most part highly siliceous muscovite-granulites, which are resistant, competent strata. They curve over in sweeping flexures and show a faint lineation which is parallel to their easterly fold-plunge and to the direction of elongation of the neighbouring rods. The rodded beds are mainly semi-pelitic muscovitic quartz-schists and granulites in which not

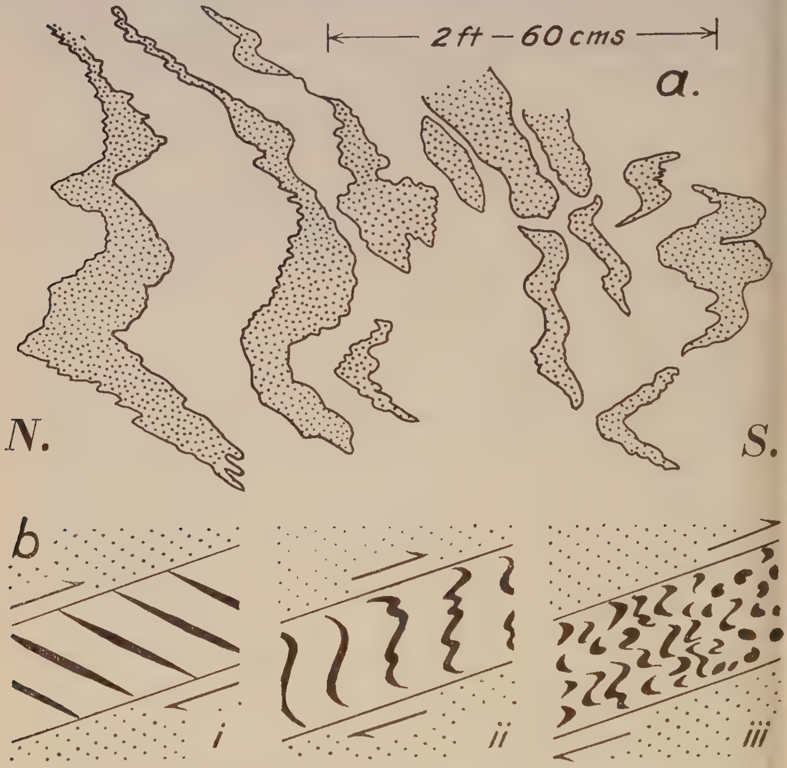


Fig. 9 *a*. Deformed quartz-filled tension-fractures, Ben Hutig, looking eastwards. *b*. The development of quartz-rods by deformation of quartz-lenses.

only small-scale rucking but also pronounced drag-folding can be observed. On the outsides of folds the quartz-inclusions commonly show stretched and platy forms (Fig. 8 *b*); where the beds have been crushed together and contorted near the fold-core, or where a flexure-fold is broken by the development of shear-folding, true rodding may be strongly developed.

Rodded pelitic mica-schist crops out on the main ridge of Ben Hutig about 300 to 400 yds. (350 m.) north-north-west of the summit (Plate 8B). The rodding in this type of country-rock is less spectacular than in the semi-pelitic granulites; the rods are discontinuous and are often platy, many of them have an elongated lens-form, others are crescentic in cross-section. Their direction of elongation and their plunge are, however, concordant with those of the better-formed rodding seen elsewhere on the mountain, and are also parallel to the plunge of the local folding. The stumpy, poorly-developed shape of these rods has resulted from the incompetence of their host-rock in which elongated quartz-filled fractures were unable to form; also, when these incompetent rocks were distorted, they were unable to force or mould the quartz-segregations into true rods, because of their yielding, plastic, or even viscous, state. The siliceous granulites, on the other hand, had sufficient strength to resist small-scale deformation during the orogenic movements, and though they have folded and have also cracked so that they now contain quartz-veinlets, their competence was enough to prevent those segregations being converted into rods.

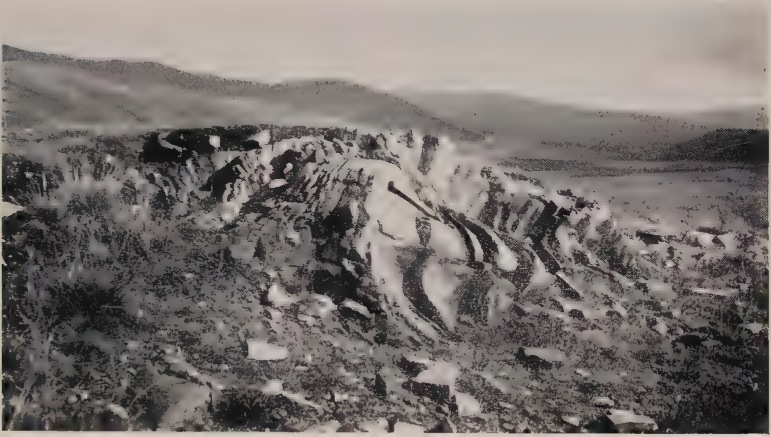
(d) **The Megascopic Symmetry of the Rods.** The monoclinic structural symmetry of the rods on Ben Hutig is clearly seen on the ground and in the hand-specimen. The end views of rods of various types have been illustrated in the preceding pages, and the asymmetry of the structures seen in the plane of the paper is obvious from the drawings (Figs. 8 and 9). Rods seen in side-view, or in plan or on exposed dip-surfaces, are remarkable in their straightness. They are crossed by joints which are at right-angles to their lengths, and on either side of which the rods are symmetrical. The rods are thus monoclinic linear structures elongated normal to the plane of symmetry, that is in B, with a homoaxial plunge towards the east. The relationship of the plunge of the rods to that of other linear structures and folds between Ben Hutig and the Kyle of Tongue is shown in Fig. 5 *b*. The uniformity of the structural plunge demonstrates that any folding across the direction of rodding, such as would be parallel in trend to the strike of the Moine Thrust, is, to all intents and purposes, negligible, as far as the rodding itself is concerned. The stress-couple responsible for the folding- and shearing-movements, which in turn were responsible for the development of the rods, acted in the plane of symmetry, that is from north to south.

Farther east, near the Kyle of Tongue, the direction of plunge changes towards the east-south-east and the movement-direction must likewise have veered towards the south-south-west. This swing in the trend of the plunges accounts for the scattering of the points in Fig. 5 *b*. The kinematic picture of Ben Hutig is thus in close accord with that deduced by Coles Phillips (1937) and Wilson (1952*b*).

4. THE TECTONIC SIGNIFICANCE OF MULLION AND RODDING STRUCTURES

The mullion structures of the Oykell and the quartz-rods of Ben Hutig have much in common. They are both simple monoclinic structures showing marked elongation normal to the plane of symmetry and parallel to the local *B*-direction, as shown by fold-axes. They owe their forms primarily to tectonic movements which acted in directions perpendicular to the elongation of the structures. The direction of tectonic transport on Ben Hutig was probably from north to south, and at Oykell Bridge it was from north-east to south-west.

The structures seen in the field, and the internal fabric observed beneath the microscope, show that the Oykell mullions were developed during intense, but normal, folding with concomitant metamorphism. The rocks are *B*-tectonites showing girdles of quartz (Phillips, 1937, pl. 34, D11 to 14) about axes parallel to the elongations of the mullions, which are, in turn, parallel to the plunge of local fold-axes. Large-scale structures, small-scale structures and microscopic fabric all show the same monoclinic structural symmetry for which there is but one rational answer: the predominant tectonic movement, responsible for these structural forms and controlling the metamorphism of the rocks around Oykell Bridge, was from the north-east towards the south-west. The spectacular development of mullions at this point was probably assisted, as Read (Read & Phemister, 1926, p. 121) and Phillips (1937, p. 596) have observed, by movements associated with the Caledonian Moine Thrust acting along the lengths of the earlier-formed corrugated structures. The effect of this longitudinal slip was to form or accentuate a micaceous veneer on those preconceived surfaces—bedding, cleavage or irregular fracture—upon which the later sliding may have occurred. The rocks now weather and break away along their secondary planes of easy parting into elongated cylindroidal fragments, and the sides of the Oykell Gorge are ribbed by a gently-plunging, coarse, ripple-like lineation. One is forced to conclude that these later movements have been purely superficial in their effect on the local rocks and that the larger structures and the internal fabric of the mullions bear no relationship to those tectonic directions normally associated with the Caledonian movements.



A.—Lineation shown by plunge of drag-folds. Moine Schist near L. Craggie, Ross-shire

B.—Quartz-rods in folded pelitic schist, looking eastwards down the plunge. Ben Hutig, Sutherland

The quartz-rods of Ben Hutig show megascopic structures closely analagous with those shown by the Oykell mullions. It is, however, of interest to note that, though the quartz-rods crop out within 400 yds. (375 m.) of the edge of the Moine Thrust zone, their structural symmetry and general simplicity have not been deformed by this great dislocation. Nor, on Ben Hutig, do the country-rocks, in which the rods are contained, indicate any marked evidence of this thrust-movement, with the exception of a band of incompetent garnet-mica-schist which occurs on the summit-ridge and western scarp-face of the mountain. This schist presents signs of increasing retrograde dislocation-metamorphism as the thrust-zone is approached; but the more competent beds—the siliceous granulites, the semi-pelitic schists, and even the rods themselves which are well exposed from the summit of Ben Hutig eastwards—show structures indicative of one movement, and one movement only, and to this movement is related the metamorphism of the schists. The tectonic trend in this locality is roughly east and west, and the tectonic translation, as shown by the asymmetry of the structures, was from the north towards the south. It seems, therefore, extraordinary that the authors of the North-West Highland Memoir could have been apparently so hypnotised by the Moine Thrust and its movements that they stated, without any explanatory notes, that the folding in this area, which plunges on the average towards the ESE., 'is to be regarded as one of the structures that have resulted from the post-Cambrian movements' (p. 601). Any unbiased geologist, working across Ben Hutig from the shores of the Kyle of Tongue, would see repeated examples of recumbent or asymmetrical folds whose axes plunge gently to the east or east-south-east, and would never suspect that he was nearing a big thrust-zone lying nearly at right-angles across his path, let alone that the folds that he was passing along could be considered due to movements on that thrust.

It is perhaps advisable at this point to return to first principles and to consider the evidence upon which the direction or sense of movement in an orogenic region is based. This has been succinctly stated by that maestro of Highland tectonics, Sir Edward Bailey (1935, pp. 51–2):

> . . . direction of movement as this term is understood in Tectonics . . . *is the direction of relative movement of the more superficial layers* of the earth's crust. We shall now proceed to enumerate the criteria generally used by tectonists in determining this direction. . . . The crest, apex, hinge or close in most anticlines is higher than the root. . . . The direction of horizontal travel of the crest of an anticline, relative to the root, is therefore what we have defined as direction of movement. Where folding is of the inclined isoclinal type the crests of anticlines have travelled beyond their roots, and the isoclinal limb-dip, or more strictly its horizontal component, points backward to the direction from which the movement has come. This condition is particularly unambiguous where the isoclinal dip is neither steep nor low

> . . . the hinge or close of a recumbent anticline points, of course, in the direction towards which movement has occurred. The evidence is particularly easy to read in small recumbent anticlines. [See for example, Figs. 2, 3 and 7.]
>
> Where recumbent folding, or corresponding thrusting, is on a large scale, it may be impossible to recognise in what directions anticlines are closing. . . . In such circumstances the direction of movement of a large scale thrust is often determined indirectly; and gathering experience has taught us that it is almost the same as that shown by the smaller, and more easily read, folds of its neighbourhood.

Here then is a fundamental principle to be applied in tectonic interpretation, one which we have no right or power to ignore unless there is to the contrary *overwhelming evidence of greater validity* than that of the fold-structures actually observed in the field. Such evidence does not, in my experience or opinion, exist in the Moine area. The structures at both Ben Hutig and at Oykell Bridge indicate folding of the Moine Schists in directions—north–south and north-east–south-west respectively—which are markedly oblique to the generally recognised trend of the Caledonian fold- and thrust-movements. As has been demonstrated by Coles Phillips (1937; 1951) the metamorphism of the Moine Series is intimately connected with tectonic transport in this divergent direction. Movements having the same trend have also been recognised and found to have developed structures on a large scale in upper Strathspey (McIntyre, 1952) and in isolated localities elsewhere (McIntyre, 1951).

Our knowledge of Moinian tectonics and structures is still very fragmentary, but a preliminary pattern seems to be emerging. In the north of Sutherland the rocks of Ben Hutig and Melness have been recumbently folded on axes which plunge eastward. The small-scale folds, such as can be seen in individual exposures, are mainly overturned from north to south, thus suggesting a direction of tectonic transport in that sense. A few, however, are so oriented as to suggest that they were formed by movements in the opposite sense. The plunge-trend swings towards the south-east across the Kyle of Tongue; it has been observed to continue in this direction in the rocks of the north coast of Sutherland as far as Borgie and Bettyhill, where, on Farr Point, there is a culmination, and the plunge flattens and then changes towards the north-west. The same south-easterly trend has been noted continuously from the village of Tongue to the south of Loch Dithreibh, a distance of about eight miles. At Altnaharra on Loch Naver (Fig. 1 *a*), and elsewhere in Central Sutherland, flat recumbent folds, which plunge south-eastward, have been recorded by Read (1931, pp. 30, 54–7). Professor Read has also informed me that many of these folds are overturned towards the south-west. This same tectonic trend and movement-direction, as has been shown, is also the dominant structural feature on the south edge of the county. These three main areas have been connected by Coles Phillips' fabric studies, and a general continuity of tectonic trend throughout the Moine Series of Sutherland from A'Mhoine to the Oykell River has been demonstrated by this author, who supplemented the information plotted on the published maps of the Geological Survey with his own observations (Phillips, 1937, p. 594, fig. 5).

It appears, therefore, that the Moine Series throughout a north–south belt, across the heart of Sutherland and lying east of the Moine Thrust, possesses a fairly uniform and continuous tectonic trend and an accordant direction of tectonic transport. 'The evidence is particularly easy to read in small recumbent anticlines.' The large-scale implications of these structures still await elucidation which can only come from further field investigations. But it is of interest to note that the structures, discussed above, do not seem to be in any way related to the Caledonian movement-directions, nor does their general sense of translation appear to be affected by the great eastward bulge of the Moine Thrust—the Assynt Culmination.

This gentle upwarp of the Moine Thrust has been credited with considerable structural significance in Sutherland tectonics. I have heard it suggested (i) that the folding of the Moinian rocks were drag-folds on the flanks of this structure; this would necessitate that the south-Sutherland structures should show a direction of movement towards the north-east, opposed to the movement-direction in the northern region; (ii) that the foldings were some form of gravity-collapse away from the crest of this area of uplift; again one would expect to find the direction of movements opposed—this time outwards—on either side of the bulge; or, (iii) that the culmination and the Moinian folding (which incidentally are not parallel in trend) were nothing more or less than folds parallel to the *a* direction and resulted from the west-north-westerly drive of the Caledonian thrust-movements over the Lewisian–Torridonian foreland.

That folds parallel to the direction of movement—in *a*—are possible seems clearly demonstrated by Kvale's researches in the Bergsdalen region of Norway (Kvale, 1948), where the folds and lineations are associated with rocks subjected to *very large-scale* thrust-tectonics. But the Moinian structures show no such association; once one gets a little way east of the Moine Thrust fault-zone, structures on a north-north-easterly trend do not seem to be at all common. I myself have seen the rocks broken by minor thrust-faults which dip ESE. like the Moine Thrust, but these dislocations are of a wholly different tectonic style and direction from the predominant recumbent fold-structures of the Moine Series itself.

The uniform tectonic style, trend, apparent direction of movement and related metamorphism in those areas of the Moine Series discussed in this paper are, in my opinion, indicative that the folding of the Moine

Series here is unrelated to the north-north-easterly trending Caledonian orogen; and the marginal thrust-zone of this orogen—the Moine Thrust—is simply a fault which cuts off the direct continuity of this Moinian folding. The picture is almost analogous to the manner in which the North Channel of the Irish Sea interrupts the continuity of the Caledonian trends. The complete absence of any comparable folding—or, in fact, of any folding at all—on tectonic trends parallel to the Moinian folds, in the Cambro-Ordovician rocks or in the Torridonian, which lie on the other side of the fault-zone in the line of the Moinian structures, is strong evidence that these strata were laid down *after* the cessation of the movements responsible for the deformation of the Moine Series.

It is a fact, or a coincidence, as pointed out by Coles Phillips (1951) and mentioned in various discussions by myself, that, though Moinian tectonic trends do not show in the Cambrian and Torridonian rocks, a parallel tectonic structure does, nevertheless, occur in the Laxfordian Complex of the Lewisian (Sutton & Watson, 1951). This is well illustrated in Ernst Cloos's map (1946, pl. 9) of the lineations in the Assynt district, though one cannot agree with its interpretation which has been criticised by Phillips (1951). In the paper referred to above, Dr. Janet Watson stated (*op. cit.*, p. 290) that 'the Laxfordian Zone has suffered plastic deformation' and that this 'plasticity . . . is clearly due to the high degree of metamorphism and to the immense amount of veining and soaking by granite material that has taken place'. It may be significant that syntectonic pegmatites can be also seen in the Moine rocks near Melness and elsewhere. It is also of interest to find that Dr. Watson compared the Laxfordian Zone with Wegmann's (1935) *Unterbau*—'the seat of migmatisation and plastic structures' in an orogen. If this comparison holds, and the Laxfordian and Moinian tectonic trends be projected and connected across the mechanical hiatus of the Moine Thrust and beneath the sedimentary cover of the Cambro-Torridonian strata, we see the Moine Series, which consists of slightly metamorphosed rocks with an 'alpine' tectonic style, fitting into place as the corresponding *Oberbau*. The Moine Series and the Laxfordian of the Lewisian have, therefore, a tectonic relationship, even if they cannot be stratigraphically correlated.

The result of this study, therefore, is to support Coles Phillips' (1951) contention that there is tectonic continuity between the Moine Series and the Lewisian. It supports Read's (1934) arguments based on other grounds, which no worker has ever tried to refute, that the folding and metamorphism of the Moine Series was pre-Torridonian; and it supports Horne's ideas that the Moine Series was post-Lewisian and pre-Torridonian in age (Peach & Horne, 1930, p. 201). On the other hand, it does not favour the views of Peach, endorsed by Bailey, Kennedy and MacGregor, that the Moine Series was equivalent to the Torridonian and that its metamorphism and folding were entirely Caledonian. (See Peach & Horne, 1930, p. 199; Bailey, 1950; Bailey & Kennedy, 1952; MacGregor, 1951; Kennedy, 1951.)

In reaching these conclusions, I have tried to use geological arguments of the most straightforward kind, and have based my deductions directly on the structures observed in the field. I have followed the most simple principles for deducing the kinematic picture from the structures seen, and I have based my kinematic interpretation on Bailey's 'criteria generally used by tectonists'. That I have interpolated and extrapolated between and beyond my immediate areas, I am well aware, but it has been done with due warning to the careful reader, and in a reasonably conservative manner. I have, I admit, treated the Moine Thrust at its face value as an important but straightforward fault-zone, and not as if it were a tectonic omnipresence controlling structures in rocks far outside its immediate boundaries. I have not tried to correlate different groups of strata on the basis of metamorphic convergence or chemical sedimentary differentiation across the Moine Thrust in the face of *Gefüge* evidence to the contrary, which latter has not been disproved nor in some instances even taken into consideration. Nor have I appealed to uncommon, not to say unusual, structure- and movement-relationships to make any further point. Rather, I have tried to look at the problem of the Moine Series in Sutherland as if it were structural, capable of solution by a kinematic interpretation of the observed geometric field-structures. The answer at the moment is little more than a first approximation, there is still a wealth of information which may support or may damn the deductions drawn from the evidence so far. I realise that 'it is a capital mistake to theorise before one has data' but on the data to hand at the moment, and subject to disproof or confirmation later, I consider that the Moine Series in Sutherland was pre-Torridonian in age; and that it suffered a widespread pre-Torridonian orogeny with concomitant metamorphism. This orogenic movement, resulting in folds and *B*-structures which trend north-west and south-east, with a principal plunge to the south-east, does not show any relationship to the Caledonian movements and deserves a special name. For the time being I suggest the *Sutherlandian*, until it can be definitely correlated either with the movements of Strathspey, or with those of the Laxfordian, the last having precedence.

EXPLANATION OF PLATES 7 AND 8

Plate 7. A. Typical mullion structure with cross-joints. On the Ross-shire bank of the Oykell River between the bridges. (Photo by P. G. Cooray, 1951.)

B. End views of irregular mullions looking down the plunge. Near the 'Pump Shed', Oykell Bridge.

Plate 8. A. Plunging folds in the Moine Series, near Loch Craggie, Ross-shire. The B-axis of the folds plunges south-east parallel to the mullions of Oykell Bridge.

B. Stumpy and irregular quartz-rods developed in pelitic schist, looking eastwards, down the plunge of the rods and the folding. Ben Hutig, Sutherland.

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DISCUSSION

PROFESSOR H. H. READ congratulated the author on providing much-needed detail about the minor structures of the classic Moine localities, and on his forthright presentations of his conclusions. There appeared to be a difference between the phenomena associated with the Moine Thrust in Sutherland and in regions farther south; the difference might be due to a variety of causes—a difference in metamorphic facies, or in the trends of the two areas; possibly, too, it might be due to the difference in the geologists who had worked in the two areas. Professor Read suggested that it would help further investigation if the Moine Thrust-movement were not called Caledonian, and if the author's conclusions were presented as showing that his Sutherlandian movement was earlier than this Moine Thrust-movement. Professor Read asked what evidence was available to determine the Sutherlandian movement as acting from north to south rather than south to north.

MR. P. WILKINSON said that it was a pleasure to contribute to the discussion and acknowledgment of this paper as he had, as a student, sat at the feet of Dr. Gilbert Wilson and of the last speaker, Professor Read.

Having worked on the Moine Thrust region, east of Loch Eriboll, he was glad to be able to confirm that the evidence there was also in agreement with the hypothesis that the lineation in the Moinian rocks was in the *b*-direction, i.e., normal to the direction of translation. Time did not permit an exposition of the factual evidence.

When it came to the interpretation of these structures, however, the speaker was not in accord with Dr. Wilson. During the previous field-season he had become more and more convinced of the difficulties of ascribing a pre-Caledonian age to the lineation in the Moine.

At Eriboll there is a series of deformed sediments ('Eriboll Thrust Series') lying above the Moine Thrust Plane of Peach and Horne, but below indisputable Moine granulites, from which they are separated by a further thrust-plane. These sediments are quite unlike the local quartzo-felspathic Moine granulites and include a large proportion of pelitic material and a subordinate limestone. Indeed, in the lower portion, the quartzitic members closely resembled Lower Cambrian rocks, but nevertheless retain a strong lineation completely homologous in direction to that in the Moinian, and persisting right up to the major thrust-plane.

There is at present, however, no absolute proof of a Cambrian age of any of the members of this Thrust Series, and the undoubted Cambrian quartzites immediately beneath them, in the lower Arnaboll Nappe, show no macroscopic lineation. Appeal was being made to microfabric investigation, but data were not yet available.

Mr. Wilkinson was inclined to the view that the lineation metamorphism and overthrusting belonged to different phases of the same orogeny. It did not seem impossible to reconcile two translations normal to each other within a movement-period as long as the Caledonian Mountain-building, but very much more work was needed on this important problem.

As to the Assynt Culmination he did not think that all tectonic significance should be denied it, as it was only one expression of a more general feature of Highland Caledonian tectonics. The Loch More and Dundonnell culminations might be cited as analogous features.

DR. J. SUTTON welcomed the evidence which showed that the small-scale structures at Strath Oykell and Ben Hutig were formed by movements at right angles to their lengths; identical structures in Ross-shire appeared to the speaker to have formed in such a manner. Nevertheless, while accepting the author's conclusions from these two localities and the earlier work of Dr. Coles Phillip on the still smaller structures forming the Moine fabric, he could not agree that these results pointed irrefutably to a pre-Torridonian age for the Moine Series.

South of Strath Oykell it was possible to determine the relations of the smaller structural features to the major fold-system; the resultant picture was of a system of folding about north -south axes which might well have been a forerunner of the Moine Thrust. The thrusting, though later than the folding, can hardly have been a completely isolated event.

The analogy drawn between Moine and Laxfordian structures seemed to have some reality in Sutherland but broke down in Ross-shire and Inverness where the two fold-systems had different trends and exhibited different styles. For that reason the similarities were, in the speaker's opinion, probably accidental.

DR. P. A. SABINE congratulated Dr. Wilson on the very clear presentation of an interesting structural study and hoped it would be followed by an associated research based on lithological and stratigraphical mapping. He looked forward to the detailed presentation in print of the argument which led Dr. Wilson from his structural results to his geological conclusions. The weight of evidence against making the folding of the Moine Series pre-Torridonian did not appear to be affected by the structural evidence now brought forward. He hoped Dr. Wilson would not press a regional name for a direction of the folding in the Moines: such a name was easily established but not readily delimited and, with further advances in knowledge, only with great difficulty withdrawn.

DR. A. F. HALLIMOND asked whether the author would regard the quartz-rods as being in part miniature saddle-reefs. In that case there need be no elongation in the direction of lineation. In contrast to this, rods formed by deformation would require considerable extension. No doubt some of the cross-sections indicate further dislocation which is perhaps related to the mullion-surfaces.

MR. A. A. ARCHER (in a written communication) pointed out that the author had mentioned examples of slickenside structure, that is lineation in *a*, which had been described as mullion structure, whereas his examples in the Scottish Highlands are lineations in *b*. It seems clear that the term is used at present for two apparently similar but genetically unrelated structures. The restriction of the term 'mullion' to structures in *b* would remove any obliquity when the term was used. Would the author suggest a suitable name for the 'mullions' in *a*, for which the term 'fluting' is one already in use by some workers?

MR. C. D. OVEY (in a written communication) recorded the presence of rodding-structure recently observed in a highly-cleaved volcanic ash above the screes on Nan Bield Pass, Westmorland. In some instances the rods projected to as much as four inches (10 cms.) beyond the general rock-face. It is suggested that structures of this sort may be common in the cleaved Borrowdale Volcanic Series.

MR. D. J. SHEARMAN (in a written communication) mentioned that structures analogous to those described by Dr. Wilson have long been known from the folded Devonian sediments of North Devon in the Ilfracombe and Combe Martin area. Thin limestones are thrown into drag-folds which have been described as 'fossil trees' and 'wriggly bands'. These could be described as fold-mullions, and appear to be parallel to the general direction of folding. Certain quartz-veins, 1 to 2 ins. (2.5 to 5 cms.) in thickness, which are more or less concordant with the bedding, also occur. These are similarly thrown into drag-folds and are in turn broken up by fracture-cleavage, thus giving rise to structures that resemble the quartz-rods of Ben Hutig. Both the fold-mullions and the quartz-rods have the same structural significance, and the question arises whether or not the term 'rod' is justified. Structurally the rods are as much fold-mullions as are the limestone drag-folds.

In the same area, at West Haggington Beach, cleavage-mullions of extraordinary perfection are developed by the intersection of bedding, cleavage and jointing. They, too, are elongated parallel to the local tectonic trend.

DR. F. COLES PHILLIPS (in a written communication) congratulated Dr. Wilson on his detailed study of these interesting linear structures. The distinction of rodding from mullion-structure is valuable because the former appears to be a segregation phenomenon related to the regional metamorphism of the schists, whilst the mullions, though owing their origin to the linear structure already impressed on the rocks, seem to have arisen as a consequence of later movements from a different direction. In the schists of Start Point, South Devon, quartz-rods are in places well developed and accord in direction with other lineated features in these rocks; but all these structures seem to be related to a single set of movements and there is no development of mullioning. He was glad to note that Dr. Wilson distinguished a class of mullion which does not depend upon the presence of an actual fold within the mullion; in some of the first examples from Oykell Bridge, which he, the writer, sectioned in 1936, the direction of foliation within the mullion bore no special relationship to the outline of the surface.

DR. W. S. PITCHER congratulated the author on a clear and timely description of mullion and rodding structures. Dr. Wilson had mentioned examples of the former type occurring in the Ards Quartzite, south-east of Glentornan Lough, near Dunlewy, Co. Donegal; these had been referred to as 'mullions' by Officers of the Irish Geological Survey in the Memoir for north-west and central Donegal (1891). At this locality they appeared to be *b*-structures formed by the intersection of a system of shear-cleavages and bedding.

These mullions were intimately connected with the deformation which affected most of the components of the Donegal Granite as well as the adjacent country-rocks. Migmatitic diorites and granites are impressed with a strong lineation which locally appears in the form of mullions. Similar structures occur in the semi-pelitic schists in the district of Maas, where they plunge steeply, though the local fold-axes are nearly horizontal. Such linear structures were developed at a very late date in the plutonic history of the area, and were not directly related to the orogenic folding. The movements responsible may, indeed, have been set up by the forceful emplacement of the main body of granite.

DR. D. B. MCINTYRE said that he and Dr. Wilson met for the first time in 1949 at Oykell Bridge, when they found themselves to be in complete agreement on the geometry of the structures there and their kinematic interpretation. He said that he was delighted to have heard the present paper in which Dr. Wilson had clearly demonstrated that the mullions and rods of Strath Oykell and of Ben Hutig were normal to the single symmetry-plane of the fabric on all known scales; the mullions and rods were therefore *b*-structures by definition. Two of the varieties of mullion described are very common in highly-folded rocks and, thanks to this Association and Dr. Wilson (1946), are rather easy to understand. The irregular variety (he was not altogether happy about the term) is rather less common and seems to have a special significance. This type is formed by the intersection of curved (h01) joints on which there is often a film of mica. Although there are numerous localities in the Moine and in the Dalradian where such structures can be seen, the only locality he knew where mullions of irregular type are developed as well as or, perhaps, even better than at Oykell Bridge, was along the River Ling 1½ miles south-west of the summit of Beinn Dronaig. These magnificent mullions are in the vertical end of a major recumbent fold. The 'water-pipe' structure in the river Garry, near Cluns (where the Moine Schists are most distant from the Moine Thrust), is essentially mullions of irregular type; once again there is an obvious correlation between the development of this structure and the localised near-verticality of the bedding-planes. It seems probable that there is more than local significance in Dr. Wilson's correlation of steep beds and prominent mullions near Oykell Bridge.

Dr. Wilson was unable to give Professor Read a precise answer to his question about the *sense* of movement, just as he, the speaker, was unable to answer definitely the similar question put by Dr. Coles Phillips (*Geol. Mag.*, 1951, **88**, pp. 150–1). It would be most unfortunate if any member failed to realise that, in the present discussions on Highland tectonics, it is the *direction* and not the *sense* of movement which is of prime importance. Dr. Coles Phillips long ago provided petrofabric evidence of widespread NE.–SW. movement in the Highlands, and the speaker has recently pointed to field-evidence supporting Dr. Coles Phillips' correlation of lineations and direction of movement. Dr. McIntyre was unable to believe that, after publication of Dr. Wilson's clear description of the facts, anyone could doubt that, on the scale considered, the movement was normal to the length of the mullions and the rods.

At the time when it was believed that the 'Secret of the Highlands' had been discovered and the 'Highland Controversy' had been closed, there was a simple story to tell (Peach & Horne, 1907, pp. 463, 471, 473): The Moine Schists formed a series of great folds trending NE.–SW. and usually overturned towards the NW.; these folds were separated from the foreland by the Moine Thrust on which the movement was likewise towards the NW. Thus the reason for the existence of the thrust seemed obvious, and the dating of the movements easy. The thrust affects the Cambro-Ordovician rocks of the foreland and the alkaline rocks which cut them; the Old Red Sandstone lies unconformably on the eroded folds. Thus the thrusts and folds were considered to be a Caledonian unit in Suess' sense.

It is now known that, like the Lewisian, the Moine folds were dead when they were thrust, but it cannot be too strongly emphasised that there are no means of estimating how long was the interval between the folding and the thrusting. The comparative kinematics of the folds and the thrusts shows that they cannot be directly correlated in a single-movement picture. Of even greater importance than the movement-directions is the striking difference in style between the folded schists and the mylonites. As this difference was recorded in the North-West Highland Memoir it is difficult to understand how its significance has been overlooked for so long. The mylonite-zone has its own tectonics of overfolds, overthrusts, and lineations, which have never been adequately described or contrasted with those of the Moine Schists.

As the folds and the thrusts can no longer be considered as forming one simple tectonic unit, the old evidence vanishes alike for the lower age-limit of the folds and for the upper age-limit of the thrusts. The folds and the thrusts differ in age by an unknown amount; their relative ages are known; but the absolute ages of both are unknown. In this connection it should be pointed out that the alkaline rocks might be Permian. It is, therefore, inadmissable to argue that the folds are pre-Cambrian on the basis of the unproved hypothesis that the thrust is Caledonian. In the Northern Highlands, Regional Handbook (1948, p. 51), it is stated that the thrusts 'are older than certain lamprophyric sheets which belong to the "Newer Granite" suite of intrusions and are found emplaced along thrust-planes'. This is an argument which was not used in the North-West Highland Memoir, and the speaker said he did not know of any intrusion of undoubted 'Old Red' age which is demonstrably younger than the thrusts; if any such intrusion does indeed exist, it should be carefully re-examined to test its validity as an age-marker.The only evidence otherwise is that on the islet of Eilean Iosal in the Kyle of Tongue where pebbles of 'mylonised rocks' have been reported in a conglomerate of assumed Middle Old Red Sandstone age (Caithness Memoir, 1914, p. 79). It seems that Peach and Horne did not realise that these pebbles constituted what now appears to be the sole evidence for the upward age-limit of the Moine Thrust, and it is now uncertain whether (1) the supposed 'mylonised rocks' are true mylonites, (2) these mylonites have indeed been derived from the Moine Thrust, (3) the conglomerates are Middle Old Red Sandstone or Trias.

Not only does the new work undermine the old argument for the age of both folds and thrusts, but it destroys even the supposed reason for the existence of the Moine Thrust. It now appears that one rigid, crystalline mass has been thrust over another, just as in the Outer Hebrides one mass of rigid Lewisian has been thrust over another along the great zone of flinty-crush; the Moine Thrust no longer represents the contact between folds travelling towards the NW. and the stable foreland on which they broke. Thus a new series of problems arises: How was it that this great thrust operated in what was apparently a kratogenic block? When did it operate (for there seems to be no longer an *a priori* reason for its Caledonian age)? What are its chronological and dynamic relationships to the other great dislocations of Scotland, and particularly to the Great Glen and the flinty-crush zone of the Outer Hebrides?

Turning to the other side of the Highlands, Dr. R. H. Clark and the present speaker are re-investigating the North Esk section of the Highland Border, and although the work is not yet complete, it appears that the Cambro-Ordovician Margie rocks are folded with the Dalradian. It is abundantly clear that the Moine and Dalradian are folded together. The folding of the Highlands may thus prove to be post-Cambrian. If this is indeed the case he, Dr. McIntyre, would put forward for consideration the counter proposition that the Moine Thrust could be Middle Old Red, Hercynian, or even Tertiary, for all that is *known* to the contrary.

DR. GILBERT WILSON, replying to the discussion, said to Professor Read that he agreed that the 'Sutherlandian' folding was certainly older than the Moine Thrust-movements—as was indeed recognised by the authors of the Glenelg and Fannich Memoirs. Even if the thrusting was younger than Caledonian, he also considered that the absence of any continuation of flexuring on north-west–south-east or on east–west axes in the Torridonian and Cambrian beds to the west of the Moine Thrust meant that the folding of the Moines was earlier than the deposition of these strata. The direction of tectonic movement had provisionally been judged as north to south because the asymmetry of the majority of the local recumbent folds suggested such a translation. Until it is known whether the folds that close to the south are truly anticlines or synclines, the real sense of movement cannot be considered proved. Now that current-bedding has been observed in some of these rocks it is hoped that definite evidence on this question will shortly be forthcoming.

In reply to Mr. Wilkinson, Dr. Wilson welcomed the evidence that, near Loch Eriboll, the local quartz-rods in the Moine Series were in the *b*-direction. The development of a lineation parallel to this direction in the 'Eriboll Thrust Series' might, however, result from two alternatives: (1) The rocks were Moinian in age, and had nherited their present linear structure from one of pre-thrusting origin; or (2) the ineations in the 'Thrust Series' had developed in *a* parallel to, and as a result of, the Moine Thrust-movement. The formation of such structures has been described from the thrust-zones of Norway by Kvale, and from America by Balk. The parallelism between the rodding in *b* of the Moine Series and the lineation in the 'Eriboll Thrust Series' may thus be purely accidental. It would be analogous to the parallelism that exists between the tectonic trend seen in parts of the Lewisian, and the post-Cambrian quartz-lineations that were formed where the pipes of the Pipe-rock 'have bent over, lattened, and drawn out into ribands parallel with the direction of movement' on the Moine Thrust (Peach & Horne, 1907, p. 471).

The Assynt culmination has recently been commented on by Dr. P. A. Sabine (*Abs. Proc. Geol. Soc. Lond.*, 1951–2, No. 1490, p. 128) and it appears that this upwarp may have less tectonic significance than it has hitherto been credited with. Its ormation should not be considered the same as that of the steeply-sided Dundonnell anticline.

The relationship between the north-south trending folds-system of Ross-shire mentioned by Dr. Sutton, and the south-easterly and easterly trends of Sutherland, is one that still needs elucidating. It may resolve into a simple swing in direction with he result that the Moine Thrust cuts across the older structures at varying degrees of obliquity. The dislocation thus appears as a strike-thrust (as far as the Moinian rocks are concerned) in the south, and as a dip-thrust in the north.

There seems to be no fundamental reason why the Moine Thrust should not have broken across a series of ancient, already crystalline, rocks such as the Moines without being accompanied by visible folding. This dislocation lies in front of the main orogen and would thus correspond to a fracture in the foreland basement of the type recently llustrated by Dr. G. M. Lees (*Quart. Journ. Geol. Soc. Lond.*, 1952, **108**, pp. 1–34), but from which the associated *plis de couverture* have been removed by erosion. Dr. Wilson said that he also believed that the Moine area of northern Scotland had behaved as a rigid block during the Caledonian orogenic movements, and that the Thrust on ts western boundary had little or no tectonic relationship to its internal structure.

In answer to Dr. Sabine, the author pointed out that the structural evidence presented in the paper indicates that the Moine Series in Sutherland was folded on east–west axes by a movement which should have equally affected the Cambrian and Torridonian strata, had they been laid down at the time. The fact that they are undisturbed, except on the narrow thrust-zone, and then on north-north-easterly axes, suggests that the orogenic phase which has been termed 'Sutherlandian' occurred in pre-Torridonian times.

Dr. Wilson agreed with Dr. Hallimond that the quartz-rods were closely related to saddle-reefs in their structural setting, and that their elongation in *b* was largely a primary phenomenon, and not due to actual stretching as was suggested in the Northern Highlands Regional Guide. Extension in *a*, parallel to the direction of movement, does not tend to yield rods of equidimensional cross-section, but rather attenuated ribands as mentioned above.

Mr. Archer's suggestion that coarse slickensiding in *a* had in the past been confused with mullions in *b* was correct: and the author agreed that 'fluting' or 'grooving', already in use for exaggerated glacial striae, might be adopted to describe such structures as were gouged out parallel to the direction of movement.

Mr. Ovey's observation of quartz-rods on the Nan Bield Pass in the Kentmere valley of the Lake District is noteworthy, and it is hoped that other examples together with their kinematic setting will in the near future be recorded. Since this paper was written the author has himself seen embryonic rods of crystalline calcite occurring on weathered surfaces of Carrara Marble in the Apennines. They were derived from sheared calcite-veinlets in a manner similar to that described for the formation of the quartz-rods.

Mr. Shearman's comparisons of the structures in North Devon with those described in the present paper support the author's view that both the rods and mullions were dominantly *b*-structures. The region of North Devon has been described by Marr a 'having all the mechanical structures of true schists, without possessing their peculiar chemical composition' (*Geol. Mag.*, **35**, 1888, p. 221), and the structures mentioned b Mr. Shearman are indisputably the products of movements normal to their axes o elongation. It is true that fold-mullions and quartz-rods do have the same structura significance, but in view of the easily recognisable difference in origin of the materia of which they are composed, the author considered it advisable and useful to distinguish between the two.

It is of interest to note that Dr. Coles Phillips considers a second movement to b necessary to produce clean-cut mullions of the types described. At Oykell Bridge suc movements may have occurred along the earlier formed *B*-axes; but in other areas, fo example in the Ross of Mull, where mullion structures occur locally, there is no evidence of late shearing parallel to the main fold-trend; though it does seem probabl that the Moinian rocks there were affected by more than one period of movement The author had had the privilege of going over some of the Start Point ground unde Dr. Coles Phillips' guidance. He had been much impressed with the way in whic quartz-rods and other linear structures were parallel to the main east–west fold-axe as declared by the normal methods of geological mapping. As in North Devon, ther seemed to be no doubt but that the major and minor structures here were completel accordant, and the various linear structures were normal to the direction of movement

Dr. Wilson welcomed Dr. Pitcher's remarks and his exhibit of mullions from th type-area in Donegal. It was of the greatest interest to know that the developmen of the structure could be tied down to a special phase in the complex tectonic histor of that area. It was also important, he considered, to note that, though the mullion described by Dr. Pitcher were *not* parallel to the major fold-structures, they wer nevertheless *b*-structures in relation to the movement responsible for their formation

Dr. Wilson found himself in agreement with much that Dr. McIntyre had said. Th time-relationship between the folding of the Moines and the movement on the Moin Thrust was indisputable; the folds were not only dead but cold when the thrusting too place. He also agreed that the rigid style of the Thrust-structures was in marked contrast with the plastic plications characteristic of the Sutherland Moines. However, eve if, as Dr. McIntyre hypothesised, the Moine Thrust were not Caledonian in ag *sensu stricto*, there is still difficulty in raising the upper age-limit of the Moinian folding, because, as pointed out above, the severed axes of the folds point directly toward the unfolded Cambrian and Torridonian strata which lie on the other side of a simple mechanical dislocation, the Moine Thrust.

Some of the points raised by Dr. McIntyre regarding the actual age of the Moine Thrust lie outside the general scope of this paper; nevertheless they are distinctly thought-provoking. At present Read's (1934) correlation of the post-Cambrian intrusions of Loch Borrolan, etc., with the Ben Loyal (Beinn Laoghal) mass ties down the upper age of the movements, because fragments of the Ben Loyal syenite occur in the post-Moinian conglomeratic outliers near Tongue (Caithness Memoir, p. 77–8). Unless it can be proved that these outliers have an age other than Old Red Sandstone it seems unlikely that the Moine Thrust was not Caledonian. Also if, as is believed, the continuation of the Thrust passes southwards between the Lewisian–Torridonian complex of Iona and the Moinian rocks of the Ross of Mull and Gribun, its age must antedate the emplacement of the Ross of Mull granite. This granite is generally accepted as being of Old Red age because it is cut by dykes 'of the usual Lower Old Red Sandstone facies'; and pebbles of granite occur in the Triassic conglomerates of Gribun, and Inch Kenneth, Mull, and in the Lower Old Red Sandstone conglomerates of Oban ('The pre-Tertiary geology of Mull, Loch Aline and Oban.' *Mem. Geol. Surv. Scot.*, 1925, p. 45).

The fact that the Cambro-Ordovician Margie rocks were folded with the Dalradian is not altogether surprising. All workers are agreed that the Dalradian rocks were extensively involved in the Caledonian orogeny, but one wonders whether that was the only period of diastrophism that these rocks have suffered. Folding on axes oblique to the Caledonian trend has been recorded in the Dalradian by Dr. McIntyre himself, and the reason for these divergent trends still awaits explanation. Until a good deal more is known about these rocks, their complex metamorphic histories and their structures, it seems premature to base too much reliance on conditions at and near the Highland Boundary.

THE ROSSES GRANITIC RING-COMPLEX, COUNTY DONEGAL, EIRE

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SUMMARY.—Within the district of the Rosses, on the west coast of Donegal, the Donegal Granite can be dissected into numerous components. An older migmatitic granodiorite forms the country-rock to a cross-cutting circular intrusion of granite, which has sheets of microgranite tangential to its contact. This main intrusion consists of three similar granites with ring-like outcrops generally separated by sharp and steeply outward-dipping contacts. An episode of porphyry-dyke intrusion intervenes between the second and third phases of granite intrusion. A mechanism of cauldron-subsidence is thought to control emplacement but, in detail, the contacts are markedly angular and this is considered to be due to the influence of the master-joints on the bounding fractures of the subsiding blocks. This joint-system was consistently imposed on each granite as it cooled. The granites exhibit weak flow-structures and a very high degree of modal uniformity is recorded, emphasising their magmatic character. There is evidence to suggest that they were still mobile when in the state of viscous crystal-mushes.

1. INTRODUCTION

(a) **General**. The district of the Rosses is situated on the west coast of Co. Donegal and lies between the town of Dunglow and the village of Lough Anure (Fig. 1); and is contained within the area of Sheets 9 and 15 f the Geological Survey of Ireland. It forms a low coastal platform which, to the east and south, terminates in a partial ring of inland hills. To the west nd north, the Rosses (*Ros*—Gaelic, promontory) are bounded by one f the most rugged coastlines in Donegal; there are many inlets and headands, fringed by numerous islands, the largest of which is Aranmore.

The topography is subdued and rounded; numerous loughs occupy rock-basins; scattered patches of drift and moraine are locally built to the proper shape of drumlins, and striated surfaces everywhere add to the evidence of glaciation. Much of the district was naturally covered with peat, but indiscriminate use of this fuel over several centuries and by a numerous population has resulted in much of the bare rock being exposed. Granitic rocks occupy the entire district and form part of the varied complex generally known as Donegal Granite. In the Rosses these granites provide a unique stage in the plutonic history of that body, for here an early tonalitic migmatite forms the country-rock to a granite ring-complex some five miles in diameter.

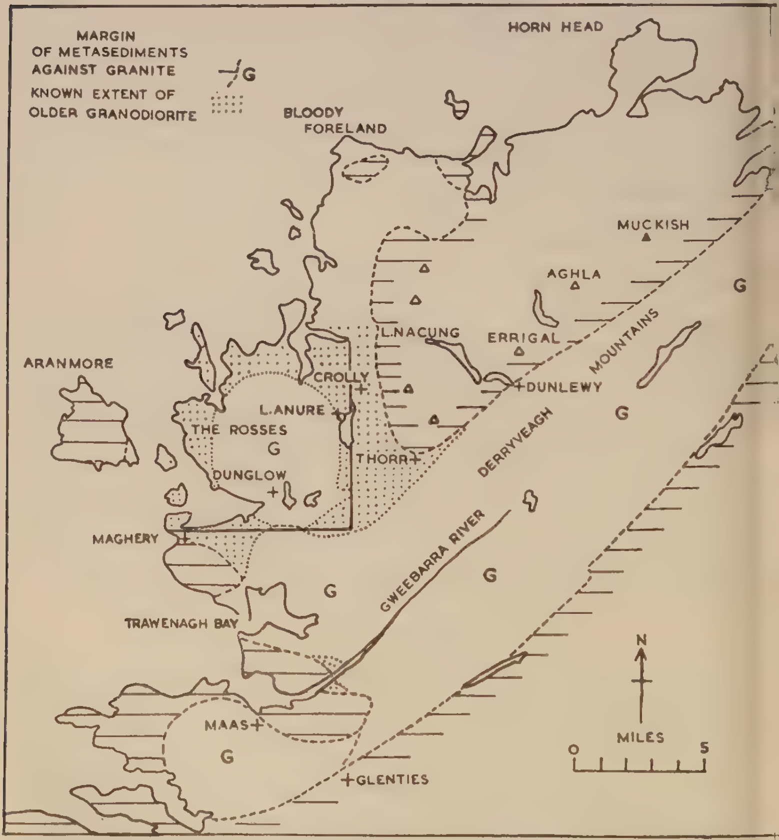

Fig. 1. Sketch map of North-west Donegal showing the position of the Rosses District in relation to the main outcrop of the Donegal Granite

Sufficient reference is made to the early history of research in a descrip-
ion of the adjacent districts of Thorr (Pitcher, 1953) and Trawenagh Bay
Gindy, 1953). The few available details are summarised in the Memoir to
heets 3–16 of the Geological Survey of Ireland (pp. 71, 72, 84, 85).

(b) **Summary of events.** Within the Rosses district the migmatitic older
ranodiorite of Thorr type (Pitcher, 1953) everywhere forms the country-
ock to a large circular intrusion. This latter consists of three similar gran-
es with ring-like outcrops generally separated by sharp and steeply-
ipping contacts. The granodiorite is also cut by a series of parallel and
teeply-dipping microgranite sheets which are approximately tangential to
e main granite. The order of emplacement of the ring-complex is as
llows:

1. A considerable number of microgranite sheets ranging from grey biotitic
ocks to much paler varieties; the more basic types were probably the first to be
truded. Emplacement of important sheets of a porphyritic microgranite formed
later phase.
2. A medium-grained granite (G1) which now forms the outer ring. A slightly
rlier and finer-grained outer portion (G1A) is locally present.
3. A coarse-grained granite (G2) which now forms an intermediate ring.
4. A north-trending porphyry-porphyrite dyke-swarm.
5. A medium-grained granite (G3) now forming the central mass.
6. A muscovite-rich granite as a phase of G3, and as a separate intrusion (G4)
the form of a small boss and several dykes. Extensive alteration akin to grei-
nisation is associated with this late episode.

The granite ring-complex, which is later than the regional metamor-
hism and earlier than the Carboniferous, is of the same general age as
e Caledonian Newer Granites of Scotland.

Several olivine-basalt dykes traverse the area and represent an entirely
parate igneous event of Tertiary age.

2. THE FORM OF THE COMPLEX

(a) **The microgranite sheets.** The microgranite sheets, which form the
rliest intrusions cutting the older granodiorite, have a dominant north-
sterly trend and a north-westerly dip. They fringe the margin of the ring-
mplex and often lie approximately tangential to the circular contact
late 10). Taken over the whole area, their general trend forms an arc, the
ntre of which lies to the south-east and outside the Rosses district. Of
e main petrological types the more abundant, the pale microgranite
eets, which are similar in type to the main granite, form the most
gular intrusions; both the darker coloured and the porphyritic types
nd to be less uniform in outline, less linear and less persistent along the
rike.

The parallelism of the main microgranite sheets makes it difficult to decide on the relative ages of the several types of sheets. Porphyritic microgranites can be seen to cut across pink microgranites at several localities but no such relationship with the darker grey microgranites can be clearly demonstrated, although they are considered to be the earliest of the suite From their close association, the various sheets are clearly to be considered as almost contemporaneous.

Everywhere the main granite, G1, shows steep and knife-sharp contacts with sheets of all three types. At a few localities xenoliths of such microgranites are found near the outer contacts of G1, as, for example, near the road east of Lough Awollane.

The sheets are most extensively developed in the north-west of the Rosses in the vicinity of Burtonport and Kincasslagh. Here they are more regular and parallel than elsewhere and occur within a belt extending a mile from the granite contact. There is a considerable range in thickness but, with the exception of the porphyritic microgranite east of Burtonport, this rarely exceeds 150 ft. The individual sheets may narrow, divide or anastomose, yet they retain an overall parallelism and remain generally tangential. An outward and northerly dip is general; the inner sheets are always steep (60–75°), agreeing with the attitude of the main contact. In the outermost sheets lower dips are sometimes recorded, i.e. 30–45°. The porphyritic microgranite, which extends from east of Burtonport into the island of Inishfree, is the largest of these sheet-like early intrusions and has a fairly uniform thickness of some 600 ft. Throughout its length of over three miles it exhibits steep north-westerly dips which are always greater than 70°.

To the north and north-east the sheeting is less regular and the larger intrusions are restricted to a narrow belt along the granite boundary Contacts with the granodiorite always dip steeply north and a general easterly trend is apparent. South of Mullaghduff these irregular sheets are thus parallel to the northern margin of the granite, but farther eastward a clear discordance appears where the main contact swings to the south-east (Plate 10).

In the east and south-east the granite cuts across two important microgranite sheets which are to be regarded as direct but early apophyses of it; one occurs at Lettercaugh and the other at Crovehy. Near the main contact these sheets strike normal to this boundary but in their eastward extension they are deflected to the east-north-east, a trend which characterises both the major and the many minor sheets throughout this area. The dip is again northerly but is now at lower angles, between 35° and 45°. The maximum thickness of the Lettercaugh microgranite is 250 ft., and that of Crovehy, 700 ft.; these thicknesses are exceptional for the sheet-intrusions in general. In Crovehy the bottom part of the larger sheet is crowded with xenoliths of the various types of country-rock. These have sharp angular

porphyry dyke-swarm and on the west coast of Cruit it invades a porphyritic microgranite sheet. Among those intrusions, lying outside the ring-complex, these particular dykes are undoubtedly late, but a few small xenoliths of similar material contained in the outer granite, G1, suggests that even they were emplaced before this granite.

(b) **The main granite-complex.** The circular granite-complex consists, in the main, of three clearly separated components, G1, G2 and G3, each of which is remarkably homogeneous in itself (Fig. 2 and Plate 10). The

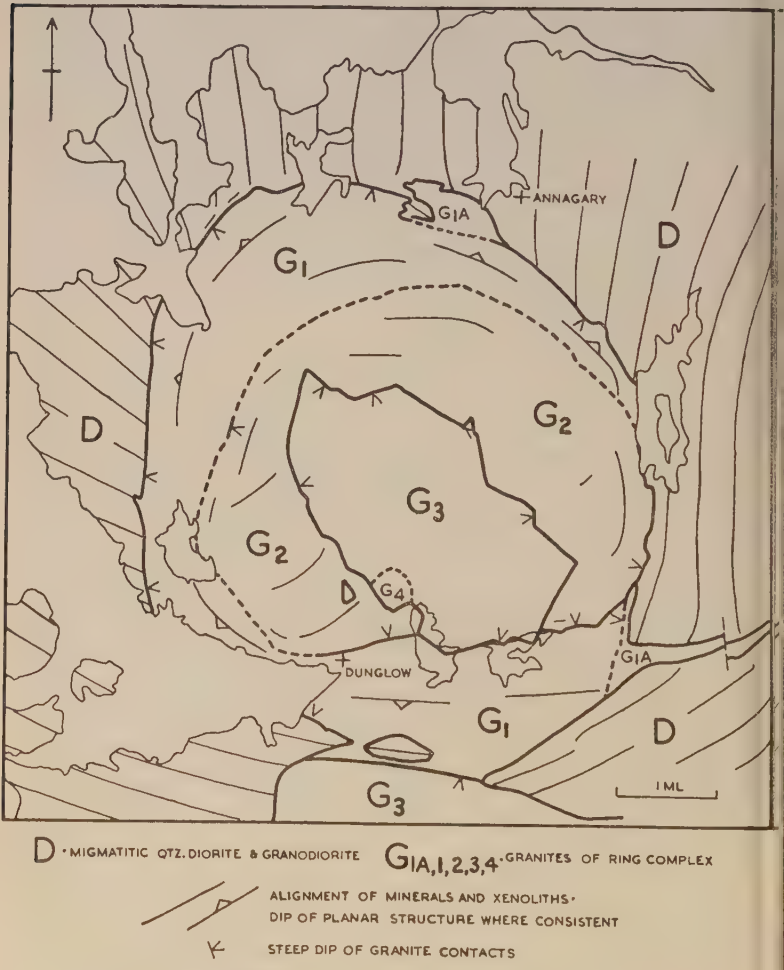
ANNAGARY
G1A
D
G1
G2
D
G3
G2
G4
D
DUNGLOW
G1A
G1
D
G3
1 ML
D · MIGMATITIC QTZ. DIORITE & GRANODIORITE
G1A,1,2,3,4 · GRANITES OF RING COMPLEX
ALIGNMENT OF MINERALS AND XENOLITHS ·
DIP OF PLANAR STRUCTURE WHERE CONSISTENT
STEEP DIP OF GRANITE CONTACTS

Fig. 2. Outline structural map of the Rosses District

complex is almost five miles in diameter; an inner misshapen ring, outlined by the boundary between granites G1 and G2, measures some $4\frac{1}{2}$ x $3\frac{1}{2}$ miles and the innermost granite, G3, forms a crudely re-entrant polygon of dimension $1\frac{1}{2}$ x 3 miles. A minor component, G4, occupies a small part of the outcrop of G3.

(i) *The outer contact of G*1. The outer contact against the migmatitic older granodiorite is very distinct and dips outwards at angles between 60° and 75°. The earlier microgranite sheets are sharply cross-cut and even the porphyritic microgranite of Burtonport is easily shown to be truncated.

In the south the place of this outer contact is taken by the cross-cutting granite of Trawenagh Bay (Gindy, 1953), shown later to be similar in type and equivalent in time to the central granite, G3.

The main outermost contact of G1 is knife-sharp; the older granodiorite is quite unmodified though the granite, G1, may show a slight decrease in grain-size near the contact; inclusions of the country-rock are rare. There is no veining and the junction is normally a perfectly plane surface. When the contact is viewed as a whole (Fig. 2), a linear form is evident leading to a crude polygonal outline, a feature emphasised in the instances of the later granite contacts.

Though the greater part of the outer contact is between the medium-grained granite, G1, and the older granodiorite, a fine-grained granite, G1A, locally takes the place of G1. In the north of the complex, west of Moorlagh, this forms an outer zone exhibiting traces of an inner boundary with the medium-grained variety. The great microgranite sheet of Crovehy is probably the equivalent in time and type of G1A, and here again traces of an inner contact, G1A against G1, are present. A very definite and steeply outward-dipping contact can, in fact, be followed for a short distance south of Meennamarragh, and this probably continues southward.

These inner contacts between the two earliest upwellings of the Rosses Granite are characterised by the large *angular* blocks of the granodiorite which lie at the contact of G1 and G1A, just within G1A. The western part of the fine-grained granite of Moorlagh constitutes a special case, for here it encloses a huge raft of the granodiorite complete with its early microgranite sheets. North-east of Lough Awollane this has been dissected into smaller rafts, one of which actually lies in G1, yet it is enclosed by a thin skin of G1A which is in sharp contact with G1. Immersion in two slightly separate upwellings of granite is thus demonstrated.

(ii) *The contact of granites G*1 *and G*2. The contact between the medium-grained G1 and the coarse-grained G2 is easily recognised, yet it varies from a rapid transition to a sharp and clearly visible junction. Transitional contacts over distances up to 100 yds. are common along the northern and north-eastern boundary; to the west, narrower transitional zones are characterised by lenticular masses of pegmatite; in the south, sharp contacts are general and are especially well seen on the shores of Long Lough and to the west of Lough Craghy. At these localities a thin zone of pegmatite sometimes fringes the contact, and the large potash-felspars of this fringe project into G2. The veining of one granite by the other is never seen. Viewing the boundary as a whole the tendency to form straight contacts is apparent and a rectilinear outline is again produced.

In the east of the Rosses the outcrop of G2 breaches the ring of G1, thus coming into direct contact with the older granodiorite. This sharp contact dips eastward at shallower angles near 45°; it is sometimes fringed with a thin zone of pegmatite. Eastward of this breach the granodioritic country-rocks are intruded by several minor bosses of a coarse granite of G2-type, the larger of which occur at Croaghacullin, Island Trairagh in Lough Anure and north of Crovehy hamlet; G2 is here presumably at no great depth.

(iii) *The contact between granites G2 and G3*. The boundary between the coarse-grained granite, G2, and the fine-grained G3, is always absolutely sharp with steep outward dips near 70°. Veining of one granite by the other is never seen. Sometimes a thin pegmatitic fringe is present with the felspar crystals projecting into the younger granite, elsewhere a finer-grained margin is present but, as a rule, the contact simply lies between the two unmodified granites. A special case exists where a two- to three-inch strip of microgranite separates the two rocks; this has a straight outer contact and an irregular, though sharp, inner contact as if a continually moving magma had resorbed an early chilled phase.

Many parts of the contacts are perfectly straight over distances of up to a mile, producing in the sum the highly angular outline of a re-entrant polygon. These contacts frequently follow certain preferred directions (Fig. 4), suggesting that the shape of the intrusion was controlled by an early system of fracture-planes, a point that will be returned to below.

In the south, G3 breaks out of its envelope of G2 and comes into direct contact with G1. Again a clearly defined boundary is present, which is always fringed by a thin zone of pegmatite (Plate 10). The mapping of this contact between granites of similar grain-size was facilitated by the obvious presence of muscovite in G3.

In the southernmost part of the Rosses, G3-type granite appears once again south of a long east–west contact against either older granodiorite or G1 (Plate 9). This boundary of the Trawenagh Bay Granite (Gindy, 1953) dips north and is marked for part of its distance by a pegmatitic fringe.

(iv) *The distribution of the muscovite-rich granites*. Within the outcrop of the central granite certain areas are particularly rich in muscovite, as indicated on Plate 10 by the double stippling. In the northern part a broad belt of muscovite-granite extends to the south and east of Meenbannad Hill. In the south similar rocks form the low hill of Altcrin, whilst white mica occurs sporadically in a broad belt along the southern contacts of G3. The margins of the two more important areas are usually gradational yet so sharply defined that there is often only a few feet of transitional rock between the two types of granite. At a few points definite contacts exist. Thus, on the north side of the hill of Altcrin, there is a steep contact between the muscovite-rich granite and the normal G3-type. The former is finer grained at this junction as it is also along its southern boundary with G3 (Plate 10). Although the remaining contacts are poorly exposed the Altcrin mass is interpreted as yet another intrusion and designated as granite G4. The two muscovitic dykes, cutting G3 north-west of the Bunerwa Loughs, confirm that such a late magma existed. Moreover, where these dykes enter the northern belt of muscovite-granite, large flakes of muscovite appear in the dyke-rock along with quartz-mica veinlets. Clearly some of the white mica is the result of a late replacement process akin to *greisenisation*. This is confirmed by the fact that locally quartz-muscovite veinlets ramify through the granite, and joints may act as the loci of alteration (Fig. 3). In Sheskinarone the process of greisenisation was locally intensified at the contact of G2 and G3 and here beryl appears abundantly. Thus the formation of muscovite-bearing rocks probably extended from the late magmatic stage until the production of joints in the cooling granite.

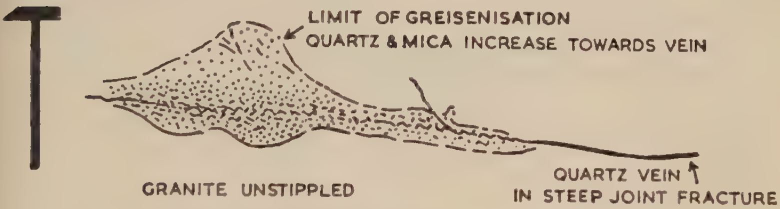

Fig. 3. Joint-fracture acting as locus of greisenisation; ¼ mile north of Altcrin, Sheskinarone

Immediately south of Dunglow a similar belt of muscovite-rich granite, here garnet-bearing, occurs along part of the contact between G1 and the Trawenagh Bay Granite, which latter is equivalent to G3. The white mica is entirely restricted to the outcrop of G3, G1 is quite unchanged and the mica is thus interpreted as having crystallised from a magmatic phase.

Possibly connected with this late phase of activity are the comparatively rare garnet-bearing pegmatitic and aplitic dykes which locally cut G1 and G2.

(v) *The porphyry-porphyrite dykes.* A swarm of north-trending porphyry dykes cuts the older granodiorite and the granites G1 and G2 but never penetrates into G3. These dykes show a slight radial trend with a convergence on the centre of the complex. They vary from 30 ft. to a few inches in width, four feet being an average, the greatest thicknesses are recorded farthest from the centre of the complex. Individual dykes may vary in width along the strike and often divide up into several parallel members. A dyke may thin out altogether or be continued by a new dyke *en échelon*. The attitude is uniformly steep or vertical.

Each group of dykes is highly persistent and often traceable for several

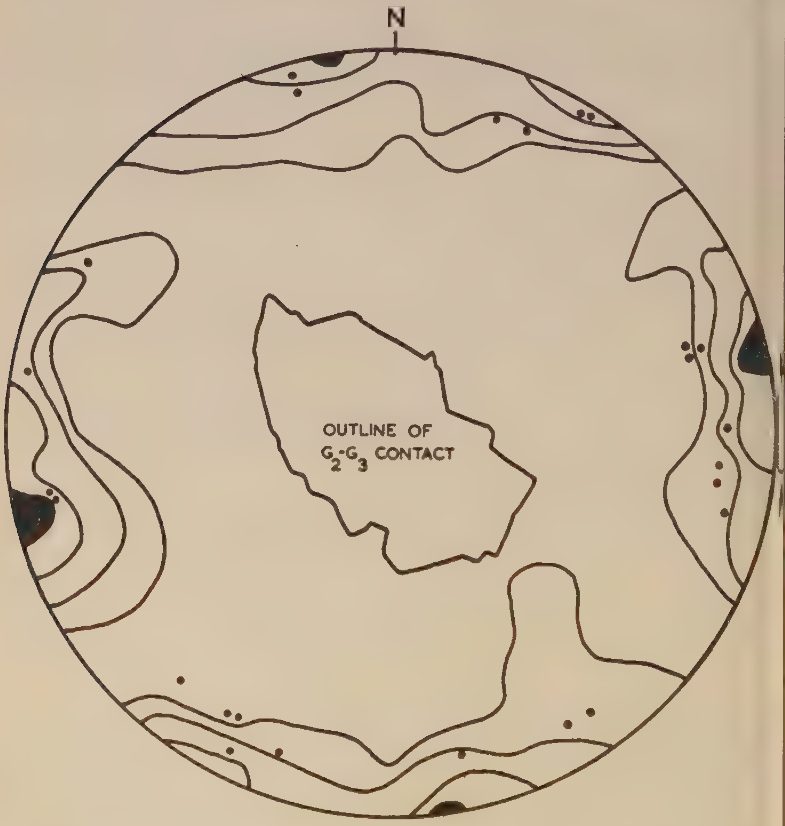

Fig. 4. Stereographic projection on the lower hemisphere of the poles of 120 joint planes in granite G2. Contour intervals in per cent: 0–1–3–6–9. The outline of the contact, G2–G3, is superimposed on the projection, and the projections of the poles of the important contact planes are represented by the heavy dots

miles. In detail the contacts are absolutely sharp against unmodified granite or granodiorite, the thicker dykes showing a chilled margin of darker and finer-grained material while thin members consist wholly of this chilled phase.

The form of these dykes is obviously controlled by fractures akin to jointing. As will be shown, the present north–south master joint-set has the same radial trend in respect to the centre of the complex (Fig. 8) and the presence of a regular step-like angularity in the dyke-walls indicates that the dykes were intruded into highly jointed rocks.

The dykes are earlier than the emplacement of G3; although they fall off in number and thickness toward this central granite, some can be followed to within a few feet of outcrops of the latter into which they never pass. South of Lough Nawaugh, for example, a swarm of dykes converges and terminates at a marked angularity in the G2–G3 boundary, and south of Dunglow the granite, G1, and the intrusive dykes are clearly cut across by a granite of G3-type.

Both in the mode of their occurrences and in variety of composition, the dykes of the Rosses exactly match those associated with the granite ring-complexes of Argyll (Bailey & Maufe, 1916). The angularity of the dyke-walls, the inward falling off of the number of dykes (*loc. cit.*, p. 164, fig. 29) and the failure to penetrate the inner granite characterise both swarms. The width of the Rosses swarm does not, however, approximate to the width of the entire ring-complex, although it is only slightly less than that of the inner granite G3.

(c) **The structural control of intrusion.** A structural control of intrusion is evident from the time of emplacement of the first tangential sheets to that of the central granite with its rectilinear outline. In Fig. 4 the poles of the important stretches of straight contact—G3 against G2—are plotted on the same spherical projection as the poles of the joint-surfaces observed in the enclosing granite, G2. There is a sufficient coincidence of the master-joint directions and the trend of these contacts to make it a reasonable supposition that these contacts were controlled by an early-formed joint-system or by fractures produced by the same causative forces; indeed, there seems no other explanation for the perfection of these plane contact-surfaces.

The joint-pattern of G2 is not markedly different from that present over the whole complex (Fig. 8), consisting as it does of two sets of joints, one north–south and another east–west. The direction of porphyry dykes agrees exactly with the present north-trending set; they were certainly intruded into joint-like fractures; even their slightly fan-like disposition reflects the same feature in the distribution of joints.

The outermost boundary of the granite-ring also has stretches of straight steeply-dipping contacts. Some part of this boundary may be controlled by the common joint-pattern; it is tempting to consider the long north–south contact on the western side of the complex as coming into this category.

A possible clue to the structural control of the emplacement of the north-east trending sheets is to be found in localities just south-east of the present area, where similarly orientated sheets run parallel to the main contact of the Donegal Granite (Fig. 1), which itself lies along the structural trend of the whole region. A small sinistral displacement of the dyke-walls suggests that intrusion took place along early shear-fractures initiated by the shouldering in of the main granite, then far below. It may even be that the joint-system was also the by-product of such forces.

In the sequel it is considered that *cauldron-subsidence* is concerned in the mode of emplacement and it is the present hypothesis that in the Rosses Complex the bounding surfaces of the subsiding blocks were commonly the important *joints.*

4. THE COMPONENTS OF THE ROSSES COMPLEX

The country-rock of the complex is everywhere the biotite-rich granodiorite of Thorr type (Pitcher, 1953); the early sheets and the ring-intrusions consist in general of biotite-poor microgranites and granites, whilst the rock-types of the dyke-swarm range from quartz-porphyry to porphyrite.

(a) **The migmatitic older granodiorite.** The petrography and genesis of the granodiorite and its contact-relationship with the Dalradian metasediments have been previously discussed (Pitcher, 1953) but the necessary extension and summary follow below.

A common rock-type is a coarse-grained tonalite dominantly composed of plagioclase associated with microcline, microperthite and quartz; a high proportion of biotite is intergrown with a little hornblende, and sphene is a characteristic accessory. The dark minerals occur in small elongated aggregates and, in these and the larger elements of the felspar, a rude alignment is apparent on many horizontal surfaces. Dark biotitic streaks and lenses are associated with the numerous xenoliths of metasediments and metadolerites. The xenoliths vary in extent from oval patches of a few square inches to huge irregular rafts of many thousands of square yards including, for example, those of Polcrovehy, Lough Anure, Annagary and Mullaghduff (Plate 10).

Some areas of the granodiorite are so crowded with aligned fragments of metasediments and the minerals derived therefrom by digestion that they may be described as *streaky migmatites.* Such mixed rocks are exceedingly well displayed in the coastal townland of Tubberkeen, west of Dunglow. In other areas the xenoliths are more scattered, and along the western seaboard included material is rare and the enclosing rock becomes lighter in colour and of greater homogeneity. A small but unique occurrence of an orbicular granodiorite on the eastern coastline of Mullaghderg is specifically marked on Plate 10. It was very fully described by Hatch (1888).

Within the separated relict-masses in the migmatites of Tubberkeen, a recognisable horizon can be followed along the strike, an example of *ghost stratigraphy* (Pitcher, 1953; Gindy, 1953). A thick marble forms an important member of the several large rafts occurring along a line extending through Curran Hill to the coast at Carrickavricken; this same horizon reappears on the island of Inishall. The strike of the marble at Carrickavricken lies across this regional trend and this particular relict-mass has evidently been rotated, indicating that the enclosing migmatite was once mobile (Pitcher, 1953, p. 434). The types of metasediment and metadolerite enclosed in the granodiorite of Thorr district to the east of the Rosses have been previously described. A new feature is the presence of a few hornfelsed acid dykes and still rarer lamprophyres within the relict masses. To the west, in the Rosses, the pelitic and semipelitic hornfelses continue to be sillimanite-bearing, simple recrystallisation characterises the quartzites and marbles, whilst calc-silicate rocks are particularly rich in diopside and members of the epidote series. Where calcareous rocks are intersected by pegmatites of ring-complex age, bordering skarns are frequent in which the important minerals are garnet, idocrase and wollastonite (Pitcher, 1950); forsterite and chondrodite appear less frequently.

The composition of the granodiorite is characteristically variable as illustrated by the modes of Table I. In the district of Thorr a progressive

Table I. MODAL COMPOSITION OF THE GRANODIORITIC ROCKS

	1	2	3
Quartz	8.3	16.0	27.6
Plagioclase	64.6	39.4	26.9
Microcline	0.4	23.9	28.6
Biotite and accessories	21.5	20.2	11.7
Hornblende	4.2	NIL	4.0
Sphene	1.0	0.5	1.2

Three selected modes to illustrate the variability of the older migmatitic granodiorite:

1. Lough Agher, 1/3 mi. south of Lough Namansheefroge.
2. Ardveen, 1/3 mi. SSE. of Croaghacullin.
3. Augullies, 350 yds. NE. of north end of Lough Nagilly.

Table II. MODAL COMPOSITION OF GRANITES

	Microgranite Sheets and Dykes					Main Granites						Muscovitic Granites		
						G1		G2		G3		G4		
Averages[1]	1	2	3	4	5	6		7		8		9	10	11
No. of Samples	5	5	5	2	1	20		10		5		1	1	1
	% by Volume					% Vol.	σ	% Vol.	σ	% Vol.	σ	% Vol.	% Vol.	% Vol.
Quartz	26.4	27.5	35.2	31.3	38.5	32.1	3.8	34.3	9.2	31.7	2.8	28.3	35.8	44.2
Plagioclase	45.7	38.0	36.5	36.6	19.2	40.9	4.5	37.2	8.1	40.3	2.3	38.7	41.1	35.8
Potash felspar	20.3	30.7	25.3	25.8	39.5	21.6	4.4	24.2	12.8	23.9	4.7	27.7	21.2	15.8
Biotite, iron oxides and secondary minerals	7.5	2.8	1.1	6.3	Nil	5.1	2.6	4.1	2.1	2.7	1.4	1.3	0.5	0.3
Muscovite	0.1	1.0	1.9	Nil	2.5	0.3	0.6	0.2	0.3	1.4	0.8	4.0	1.4	3.9

[1] 1. Average of 5 dark grey microgranites.
2. Average of 5 light grey microgranite sheets.
3. Average of 5 pale microgranites.
4. Average of 2 grey porphyritic mircrogranites.
5. A typical aplitic dyke.
6. 7. 8. Average compositions of the main ring-granites.
9. Muscovite-granite of Altcrin.
10. Muscovite-granite from the Meenbannad area.
11. Partially greisenised granite from Sheskinarone.

increase in quartz and microcline is apparent from north-east to north-west; this trend appears to continue into the Rosses and is coupled with a decrease in the femic constituents. Thus, the granodiorite type of the north-western seaboard, on Cruit and Owey, becomes so rich in quartz and microcline that it begins to resemble the coarse granite of the ring-complex. It must be emphasised that these changes are gradational; the granodiorite with its characteristic lineation remains an entity in the field. It is thus perhaps significant that the textures of the microcline and quartz indicate that they are late in the crystallisation history, replacing the earlier minerals and suggesting that a late stage potash-silica metasomatism has locally converted the tonalitic rocks to potash-rich granites. Nevertheless, the close correlation between xenolith density and the basicity of the granodiorites can also suggest that the dioritic character is merely a product of reaction between country-rock and *granite*.

There appears to be little significant alteration of the granodiorite at contacts with the ring-granites, but the common but sporadic reduction of the sillimanite to white mica within the metasedimentary rafts is probably an end-stage effect connected with the cooling history of the granites.

(b) **The microgranite sheets.** The suite of early sheet-like intrusions consists of fine to medium-grained granites which vary from greyish rocks with a moderate biotite content to white or pink varieties poor in biotite but relatively rich in muscovite. A porphyritic microgranite forms a distinctive textural type. Other than a variation in mica-content, the great majority of the sheets are petrologically similar (Averages Nos. 2, 3 and 4 of Table II); the most divergent type being a grey biotite-rich microgranodiorite of restricted occurrence (Average No. 1). Xenoliths are not common though occasionally trains of angular xenoliths are orientated parallel to the walls.

With the exception of the finer grain-size, the common rock-type is modally quite similar to that composing the main granites; an oligoclase (near Ab_{75}), quartz, microcline-microperthite and one or both of the micas form the essential minerals. There is a tendency to equigranular texture with reduction in grain-size. In the porphyritic microgranites relatively large plates of microcline show irregular and pervading boundaries and frequently enclose the accompanying minerals. Muscovite and microline become more important in the lighter coloured types, the white mica occurring as robust flakes sieved with quartz. In contrast to the main granites there is a closer approach to equigranularity, the plagioclase loses its form and all the felsic minerals show equally interfering boundaries. Crude micrographic textures may appear.

Associated with the main sheet is a host of aplites and pegmatite dykes in which muscovite is abundant and garnet a frequent accessory. The composition of a typical aplite is given in Column 5 of Table II. The two textural types are generally associated in the same intrusion and an almost unlimited variation exists in their relationship. A very common case is a segregation of coarse pegmatite along the walls of an aplitic dyke, large graphically intergrown microcline crystals are interspaced with plumes of muscovite and may project and widen out into the finer-grained portion of the dyke. There is often a greater development of pegmatite on the hanging wall and Fig. 5 illustrates this and the upward collection of pegmatite below a stoped block. Veins often arise from these pegmatite segregations as if squirted out under pressure from a very mobile and immiscible fraction.

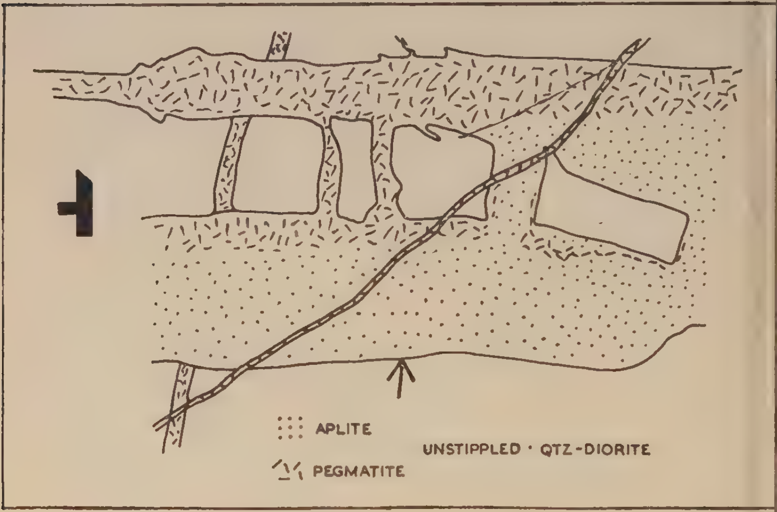

Fig. 5. Plan-view of a pegmatite sheet showing the stoping of the wall-rocks and th concentration of pegmatite on the hanging wall of the intrusion. Note especially th collection of pegmatitic material beneath a subsiding block. North–south footpath Crovehy

The fine-grained equigranular aggregate of the aplite is in strong contras with the coarse graphic textures of the pegmatite, yet the composition i identical and the difference must be attributed to the separation and differentiation of a fugitive phase.

Of the less common rock-types, the grey microgranite sheets are obviously much richer in biotite; apatite is an abundant accessory and may b accompanied by sphene. The plagioclase is here most clearly zoned with calcic core of composition near Ab_{72} and a broad outer rim near Ab_{8} The two or three grey porphyry dykes, including the partial ring-dyke o Mullaghderg, have a composition near that of the porphyries of the linea swarm described below.

(c) **The granites of the ring-structure.** The several light-coloured granites forming the ring-structure of the Rosses are very similar in texture and composition; the differences are that G2 is considerably coarser than the medium-grained types G1 and G3, and that there is a decrease in biotite-content with age (Table II). Though occasionally slightly porphyritic, the granites are more generally even-grained and very uniform in grain-size. In G1 and G3 the mean length of the plagioclase crystals is 1.3 mm. and areas of quartz have a mean diameter of 2.1 mm. In G2 these measurements are 1.9 mm. and 3.6 mm. respectively. The great uniformity of composition is worthy of special note. Part of the standard deviation for G1 and G3 is due, of course, to experimental error which must be more considerable in the case of the coarse-grained granite G3; there is, however, no doubt of its somewhat greater variability. The single chemical analysis of Table III is quite representative of G1.

Table III. CHEMICAL COMPOSITION OF GRANITE

SiO_2	72.47
Al_2O_3	15.24
Fe_2O_3	0.27
FeO	1.36
MgO	0.69
MnO	0.04
CaO	1.34
Na_2O	3.69
K_2O	3.99
H_2O+	0.06
H_2O-	0.08
CO_2	0.26
TiO_2	0.17
P_2O_5	0.04
	99.70
S.G. Bulk	2.64

Granite-type G1, quarry at roadside, south-east corner of Dunglow Lough. (Reproduced from *Quart. Journ. Geol. Soc. Lond.*, **108,** 1953 (1952), p. 427. Analysis by W. H. Herdsman).

The essential minerals in all three granites include an oligoclase-andesine, microcline-microperthite, quartz and biotite; apatite is accessory. The scattered flakes of the mica intersect all the accompanying minerals, the euhedral plagioclase crystals are moulded by the quartz and microcline which show irregular mutual boundaries. The larger plates of microcline sometimes irregularly pervade the areas between the biotite and plagioclase and frequently enclose the latter but, in general, such intricate textural relationships as are exhibited by the minerals of the migmatitic granodiorite are less well displayed.

The potash felspar is always *microcline-microperthite*, the plagioclase of which takes the form of tiny sub-parallel lenticles or rectilinear patches. Wart-like myrmekite invades the potash felspar at mutual boundaries with the plagioclase. The *oligoclase-andesine* has an oscillatorily zoned core of composition near Ab_{68} and frequently exhibits an outer zone of composition near Ab_{76}. Robust flakes of a white mica commonly replace part of this core. The *quartz* occurs interstitially or as larger compound units; it contains innumerable planes of liquid inclusions which traverse many contiguous grains; these roughly parallel sets show a preferred orientation. Signs of strain are revealed by undulose extinction and a parallel series of microscopic fractures. The *biotite* is pleochroic, commonly X = straw yellow, Y = Z = dark brownish-green. It encloses minute apatite crystals and is often associated with euhedral epidote which appears to be replacing the mica.

Biotitic patches and streaks so characteristic of the granodioritic country-rocks are far less common within the granites of the complex. They are present in relatively small number in the outer granite G1 and are here always distinctly and consistently orientated parallel to the outer contacts of the granite. Such xenolithic material is even less common in granite G2, where the degree of orientation is poor, and very rare in the central granite, G3. These xenolithic patches, a few inches or a foot or more in length, are rather finer-grained and more equigranular than is the enclosing granite. Plagioclase is here the dominant felspar and apatite is much increased. Similar material within the migmatitic granodiorite has been shown to arise as a result of granitisation of several types of hornfelses and a similar origin is suspected for many of these xenoliths in the granite.

(d) **The muscovite-granites.** The muscovite-rich granites occurring in the central area are quite similar to G3 but the biotite is much reduced or absent, its place being taken by large units of muscovite which give the rock a characteristic spangled appearance. All the minerals are distinctly idiomorphic against the quartz, even the microcline showing clear-cut crystal faces. Garnet is a sporadic accessory.

The white mica exhibits two contrasted modes of occurrence; either the stout flakes may be set quite normally in the quartz or microcline, even moulding the euhedral plagioclase, or the mica clearly replaces the plagioclase and biotite; the mica is both original and deuteric. Around the beryl greisen of Sheskinarone there is a progressive alteration of the normal biotitic granite of G3 type, which may be taken as a standard example of such changes; the final production of a beryl-quartz-mica rock associated with beryl-bearing pegmatites and quartz-veins is, however, exceptional. Towards this locus of alteration the plagioclase becomes turbid and set with increasingly robust flakes of white mica which may preferentially replace the more calcic core; flakes of haematite and grains of epidote appear. The biotite is sporadically altered to chlorite and both minerals are fringed and intersected by flaky aggregates of white mica; the biotite disappears as these aggregates are replaced by more robust flakes, some of which are intergrown with haematite. Locally and in more advanced stages of alteration, new quartz may accompany the white mica and finally the felspar is wholly replaced. Apatite, garnet and beryl appear sporadically.

(e) **The porphyry–porphyrite dyke-swarm.** The predominant rocks of the north-trending dyke-swarm form a natural transition between porphyry and porphyrite. The former are the more abundant whilst the latter type constitute many of the thinner dykes and some of the chilled edges of the porphyries.

In the more general type, numerous small phenocrysts of plagioclase, quartz, potash felspar and greenish biotite are set in a microcrystalline mosaic of microcline and quartz. The phenocrysts are generally well formed though at their margins they are minutely irregular and intergrown with the ground-mass; a highly zoned oligoclase is predominant over microcline-microperthite. Crude graphic textures may occur between the quartz and felspar of the ground-mass.

In the most basic type small phenocrysts of plagioclase and biotite are set in a dark, fine-grained ground-mass consisting of laths of plagioclase and plentiful flakes of green biotite, both of which are orientated by flow. The plagioclase phenocrysts are highly zoned and have a core as calcic as andesine. The former presence of amphibole is sometimes indicated by the flaky aggregates of biotite showing an approach to the characteristic outline.

Rocks intermediate between these types are common. There is an entire range in the proportions of plagioclase, microcline and quartz in the ground-mass, together with a considerable variability in texture. Nevertheless all are closely associated, even within a single dyke. Identical rocks with a similar variation are associated with the granite ring-complexes of Argyll where they similarly fail to cut a central granite (Clough, Bailey & Maufe, 1909, p. 641).

(f) **Conclusions relating to the composition of the granites.** The more basic varieties of the older migmatitic granodiorite are considered to be the result of reaction and mixing between the metamorphosed country-rocks and granite or granitic fluids. These rocks certainly pass by transition into more granitic types which approach the composition of the clearly intrusive and newer granites. It seems that granitic material arising from the same deep source, which was so highly reactive in its initial stages that it produced mixtures with the country-rocks, later became passive, forming cross-cutting intrusions. Another possible hypothesis is that granitisation and remobilisation of a dioritic migmatite produced the material of the newer granites (cf. Gindy, 1953).

Among the porphyry-porphyrite dykes of the Rosses the range of composition is within that of the coarser-grained members of the complex. The most acid and basic extremes were available at one time, between two phases of cauldron-subsidence. It is tempting to regard the intermediate types as *mixtures*, the extremes of which may have been provided at depth by the mobilisation of a small part of the sunken mass of migmatitic granodiorite and by the granite of the ring-complex.

The great uniformity of composition maintained throughout the history of the emplacement of the granites of the ring-complex contrasts with the variability of the older granodiorite. It confirms the magmatic character of these rocks at the present level. There is merely a small though significant variation in the biotite-content which decreases with the age of the ring-granites (Table II). Evidently any process of differentiation had all but ceased to operate before the present level was reached. The decrease in biotite might be explained by crystal settling in a supposed chamber at depth, yet from the composition of the early sheets it is apparent that granites with an even greater range of biotite-content were even then available. The obvious correlation between the abundance of xenolithic material and the biotite-content is impressive enough in the Rosses and neighbouring areas to suggest that different degrees of contamination might be one factor controlling variation.

Chayes (1952) has emphasised the great internal uniformity of the granites of New England. They are cross-cutting masses which are almost modally identical with the main granite-type of the Rosses. It is evident on a wider review that such a uniformity, even such a rock-type, is characteristic of the *late* phases of post-orogenic granites and is rarely a property of synorogenic migmatites or even the early contaminated phases of the later granites. Whatever the mode of production of the granite-magma, this might be the result of a natural convergence to a eutectic valley (cf. Chayes, 1952), although this supposes an almost impossibly perfect physico-chemical system. One is tempted to apply a similar reasoning to that widely held for the basalts—that *some* granites arise from a uniform deep layer.

5. THE FABRIC OF THE GRANITE RING-COMPLEX

(a) **Orientation of minerals and inclusions.** The minerals and abundant xenolithic masses of the migmatitic granodiorite show a marked and consistent orientation which bears no relationship to the outline of the ring-complex. Within the granites the megascopic alignment of the minerals and rare xenoliths is comparatively weak and becomes even more so in each successive intrusion.

(i) *The fabric of the older granodiorite.* The alignment of the little clots of dark minerals which is so very apparent on horizontal surfaces of the granodiorite is rarely discernible in vertical exposures, though the attitude of the biotitic schlieren and patches indicates the presence of a planar structure. The significance of the remarkable ray-like configuration shown by the generalised presentation of such data in Fig. 2 is best left until the final examination of the Donegal Granite as a whole. Though undoubtedly modified by flow (Pitcher, 1953), this planar structure certainly parallels the arcuate regional strike of the local Dalradian metasediments. Although there is a minor deviation near the northern contact, the general form can bear no direct relationship to the ring-complex, which is clearly a cross-cutting body.

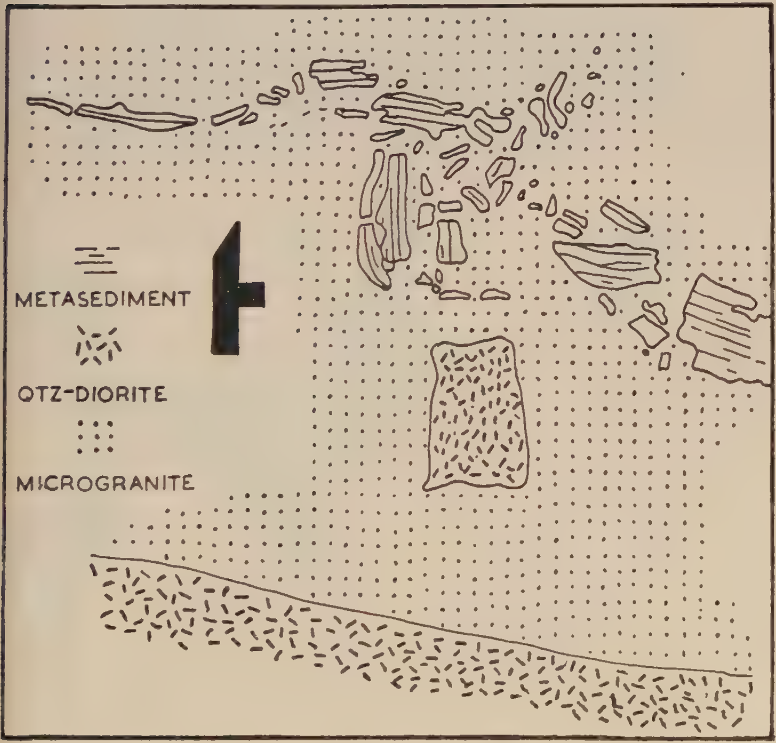

Fig 6. Xenoliths in microgranite sheet showing a pattern resembling that produced by turbulent flow. Path to Polcrovehy, Meenamarragh

(ii) *The fabric of the microgranite sheets.* In the more biotitic microgranites the mica reveals a foliation which is commonly parallel to the walls. When present the alignment of xenoliths conforms to this structure and may show swirling patterns (Fig. 6) which simulate those produced by turbulent flow. In the extreme south-eastern part of the Rosses district a foliation is very pronounced in the microgranite sheets; this structure differs from the above, being the result of cataclasis which becomes progressively more intense south-eastward, finally culminating in mylonitic rocks. This superimposed deformation is first recorded by the dykes; the granodioritic country-rocks are only affected nearer the loci of the shearing, which is in this case the contact of the main Donegal Granite. The dykes and sheets act as lines of weakness, recalling the sheared granite-dykes cutting the unchanged hornfelses of the Insch aureole, Aberdeenshire (Read, 1951).

(iii) *The fabric of the main granites.* Within the main granites megascopic structures of the above types are not well shown. In the outer granite, G1, the ovoid biotitic patches are fairly consistently aligned parallel to the outer contact and in some areas the biotite-flakes exhibit a weak but similar orientation. The dip of this planar structure is very generally steep and often directed outwards parallel to the main contact. A number of examples of the xenolithic elements are shown in the sketches of Fig. 7, where A is a

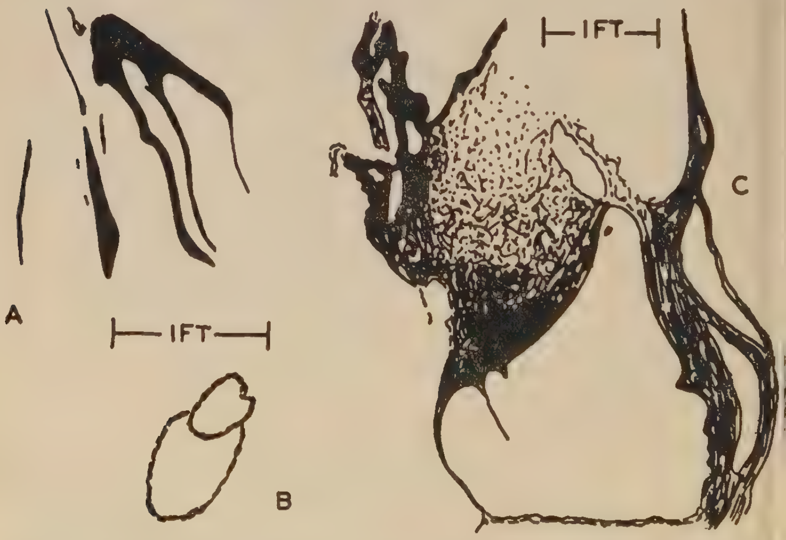

Fig. 7. Plan-view of biotitic inclusions and schlieren in the granites. A: In G2, west of Lough Anure. B: In G2, north-east of Lough Leaghan. C: In G1, south of Dunglow Lough

common type and C a more irregular type of schlieren. Sketch B shows the not uncommon ring-shape which is sometimes seen to be the surface intersection of a concave biotitic schlieren; it is tempting to regard these as parachute-like bodies propelled by flow normal to their surface. In the field all these biotitic streaks give the impression that the granitic medium had a considerable viscosity in the latest stages of mobility—a not unnatural expectation.

The rare patches in G2 are very poorly orientated although there is some approach to a circular structure within this intermediate ring of granite. A mineral orientation was not seen in this coarse rock or in the finer-grained central granite, G3.

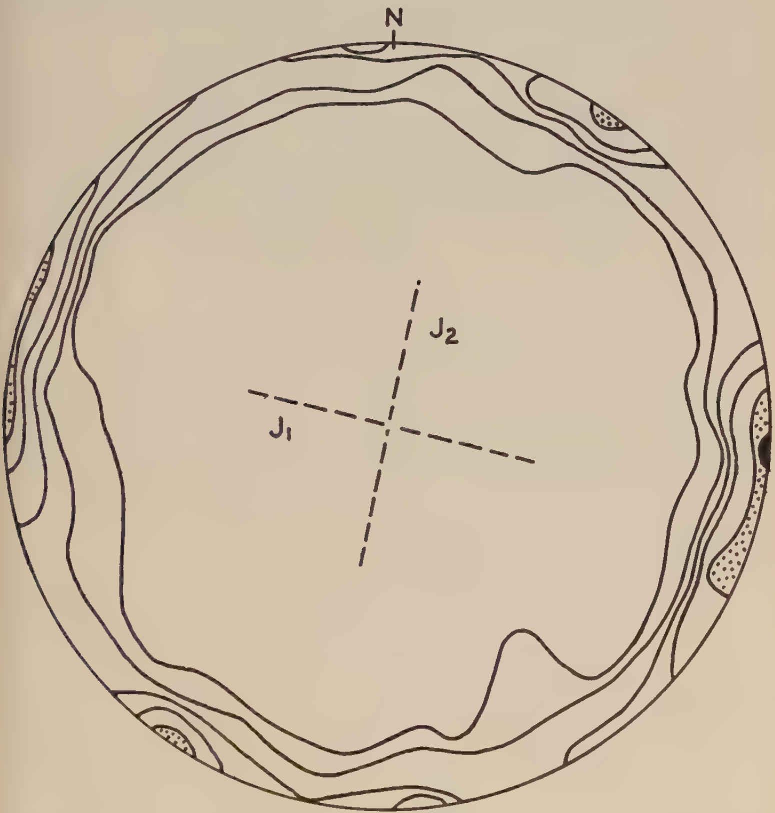

Fig. 8. Stereographic projection on the lower hemisphere of the poles of 700 joint-planes in all rock-types. Contour intervals in per cent: 0–1–2–3–4–5–6. Flat sheet-joints omitted. J1 and J2 are the central joints of the two systems shown by the double maxima

Preliminary petrofabric work on orientated thin sections indicates, however, that a definite fabric is present; these granites are not structureless, bearing out the opinion of Sander that a microfabric is rarely absent even when indeterminate in the outcrop. The normal petrofabric diagrams of biotite either exhibit girdles with horizontal axes or the opposed pole maxima indicative of a vertical plane, both axis and plane being parallel to the contact. These results could be interpreted as due to rotation or alignment of the flakes by vertical flow of the viscous magma and this hypothesis accords with the macroscopic structures mentioned above.

It is rare for the quartz not to show some sign of strain such as undulose extinction and lamellae-like fractures, although granulation is rarely effected. These phenomena record, though weakly, the outer influence of the very considerable belt of cataclasis confined in intensity to the main Donegal Granite and its immediate environs.

(iv) *The fabric of the porphyry dykes*. The late porphyry-porphyrite dykes exhibit clear flow-structures marked by thin biotitic bands lying parallel to the contact and sweeping around projections in the walls. Numerous bands are sometimes present, crowded near the contact but with widening intervals inward. Clearly these dykes with their broad chilled margins were injected in a fairly viscous state into rocks which were relatively cold and well jointed, yet the time of this intrusion lies *between* that of G2 and G3.

Near Dunglow superimposed shear structures appear in two of the dykes with the shear planes orientated at an acute angle to the walls.

(b) **Joints**. As in many other granite areas, joint-structures are everywhere apparent and are most perfectly developed in the finer-grained granites. The two main types are the unmineralised sheet-jointing following the surface topography and the much more important steeply-dipping joints, many of which are mineralised. These latter show an impressive influence on the trend of rivers and streams.

The steeply-dipping joints form a regular pattern which is consistent over the Rosses district. Fig. 8 is a projection of the poles of 700 of these joints measured without selection—selections of the best-developed joints in separate outcrops would lead to a considerable intensification of the maxima. No important difference in the outline of Fig. 8 is obtained by separately plotting either the joints of the granodioritic country-rocks or the different granites, or by relating jointing and foliation (cf. Fig. 4, p. 162). Two systems of joints are apparent, one striking slightly south of east and the other slightly east of north. Evidence of mineralisation is much more marked in the north–south joints where it takes the form of coatings of white mica; thin quartz-veins may also occupy these joints and small movements are sometimes proved by slickensiding and the offset of minor dykes.

Rectilinear inclusions of the older granodiorite in the youngest phases of the granite ring-complex prove that a joint-system was present at this early stage. The porphyry dykes were intruded into jointed country-rocks before the emplacement of G3. It has been suggested that the contacts of the granites are controlled by the joint-directions and there is a correspondence of trend between these contacts and the *existing* joints (Fig. 4). In addition, the mineralisation, especially the location of greisenisation along joints in some parts of G3, indicates that the latest of these fractures were formed soon after solidification. The total of this evidence indicates that the same pattern of joints antedated the complex and was impressed on each new phase as soon as it became solid; the controlling forces were constant and operated throughout the plutonic activity. The nature and origin of these controlling forces are not yet understood; they are certainly regional and not directly a consequence of the intrusion of the ring-complex.

The joint-system exhibited by the porphyries is often different from that of the enclosing granite; commonly two steep planes intersecting at angles near 90° are inclined at acute angles to the walls. A good illustration of the closer type of jointing in these dykes is shown by a woodcut (*Geol. Surv. Mem. Ireland*, 1890, p. 85, fig. 17).

5. MODE OF EMPLACEMENT

The granodioritic rocks were cool and regularly jointed before the emplacement of the three granites. The early microgranite sheets were intruded along steep fractures, trending parallel to the main Donegal Granite, and these were probably the result of forces initiated in the early stages of the uprise of this great mass.

The outward and steeply-dipping linear contacts of the granites of the ring-complex are thought to have been controlled by a single regional joint-pattern which was imposed on each granite as it cooled. The successive granites of the ring-complex rarely contain fragments of earlier members, and evidence for large-scale piecemeal stoping is lacking. A process of cauldron-subsidence is thus invoked to explain the emplacement; each intrusion involved the subsidence of a central block. The homogeneous magma then rose vertically and probably helped to depress the blocks by pressure on the outward-sloping sides and by filling the new reservoir which must appear above.

The first intrusion of the central complex solidified as the fine-grained granite, G1A, and this may have taken the form of a partial ring at the present level, with an inward contact against the sunken plug of older granodiorite. This is suggested by the abundance of angular masses of the latter restricted to the present contacts of G1A against G1. Further subsidence of this same block made room for G1.

Subsidence of a new block of smaller dimensions and slightly different centre brought in G2. The northern transitional portions of the contact G2–G1 could be interpreted as a zone of remobilisation and mixing, when G2 was but little below its crystallisation temperature.

A longer interval of time elapsed before the emplacement of G3, for the porphyry dykes were previously intruded into the jointed and relatively cool granite G2. The necessary openings occurred along master joint-planes, perhaps as a result of the upward stabbing force which may have initiated the subsidence of the central block. The falling-off in number and thickness of the dykes toward the centre of the complex might have been the result of compression immediately following this upward push and due to a tendency of the centre to sag just before the central block subsided. Such a compressional force would increase toward the centre of the ring progressively inhibiting dyke-intrusion inwards.

The dislodgment of the central block seems clearly to have been controlled by the master joint-planes of G2. The new magma, G3, was locally enriched in the constituents of white mica which crystallised normally. During cooling the separation of an alkali-rich fugitive phase altered the solidifying rock and even continued to circulate after joint-fractures were formed; a new growth of white mica was the result. At this late stage muscovite-rich granites also appear as minor intrusions.

Despite the presence of potential fracture-planes or even ready-made fractures the approximately circular outline of the intrusions has still to be explained. For this it seems necessary to invoke magmatic pressure originating from a point source, such as the top of a paraboloidal reservoir, as has been done by Anderson (1936) in his discussion of the general theory of ring-fractures. Perhaps an upward-stabbing force weakened a closed belt of joint-fractures, thus enabling magma to be injected as a polygonal and not a circular ring-dyke. Gravity would aid subsidence because solid granite has a greater density than the equivalent magma. It is worthy of final note that the diameter of the Rosses Granite Ring-Complex (5 miles) is of the same general order as that of many other intrusions characterised by arcuate boundaries.

Following the fundamental discovery of ring-structures by Clough, Maufe & Bailey (1909), Richey (1928) was able, by the tracing of contacts, to reveal a ring-structure in the apparently homogeneous granite of the Mournes. With these examples as a background, the tracing of many miles of contacts in the Rosses has enabled the writer to make a dissection of this part of the Donegal Granite into its numerous components which are here displayed in the form of another ring-complex with unique features.

ACKNOWLEDGMENT

The writer gratefully acknowledges the receipt of a grant from the Central Research Fund of the University of London.

EXPLANATION OF PLATES

PLATE 9

Rectangular joint-blocks of coarse granodiorite as marginal xenoliths in the microgranite sheet of Crovehy. Irregular pegmatites cross-cut the two rocks.

Near ruined farm, south of Crovehy village.

PLATE 10

Geological Map of the District of the Rosses, Co. Donegal, Eire.

Scale: 2 inches to 1 mile; 1: 31,680.

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DISCUSSION

PROFESSOR H. H. READ congratulated the author on the completion of a delightful piece of granite work and on the lucid exposition of his results. The Granite Series was invented when the Donegal work had hardly begun and it was extremely gratifying to find that Donegal was likely to supply examples of all the main terms of the Series. The Rosses Granite illustrated emplacement by repeated cauldron-subsidences and was a high level and late member of the Series. One feature of these cauldron-subsidences that interested the speaker was that they appeared to be of a fairly uniform and small size, some ten miles in diameter or less. Possibly some of the experts in the physical properties of the crust would explain why this was so. Another matter of interest raised by Dr. Pitcher was the biotitic schlieren; the shapes of these on occasion seemed to be difficult to reconcile with an origin from sedimentary enclaves. Schlieren in general invited much closer study than they had received; Professor Read had in mind particularly certain wavy biotitic bands discovered in the Newer Granite of the nearby

Lettermacaward area by Dr. Amin Gindy. Dr. Pitcher had concluded that the Rosses Granites were magmatic because of their very even grain and constant composition; the speaker, whilst not disputing the magmatic origin of the Rosses Granites, considered that this evidence did not necessarily warrant the conclusion which Dr. Pitcher drew from it. Many undoubted magmatic rocks had a very uneven grain and a patchy composition, as was to be expected; uniformity meant uniform conditions and such could arise equally well in a migmatitic as in a magmatic environment.

DR. GILBERT WILSON said that he wished to add his congratulations to Dr. Pitcher on this paper which will interest not only workers in Donegal, but also petrologists and structural geologists elsewhere. Before going into questions which he himself had considered raising, however, there was Professor Read's point on the size of these ring-intrusions. It is remarkable that they are all of the same order of magnitude, and their dimensions accord closely with those of collapse-caldera in modern volcanic regions (H. Williams: 'Calderas and their origin'. *Univ. Calif. Publ., Bull. Dept. Geol. Sci.*, **25**, 1941, pp. 239–346). In Great Britain it is possible to trace the continuity of these surface manifestations downwards through the Tertiary volcanic complexes of Mull, Ardnamurchan, etc., to deep-seated zones exemplified by Glen Coe, and now the Rosses. At all levels there is evidence of a foundering rock-plug of more or less constant diameter, which, at depth, may show a relatively narrow clearance with the surrounding walls of country-rock. Such plugs do not appear to have been found as isolated masses in the large elongated batholiths of orogenic belts, as might reasonably have been expected had they been derived from the collapse of the roofs of batholithic cupolas. Rather they appear to be associated with small-diameter pipes, up to perhaps fifteen miles across, drilled, as shown by the Rosses, at a late stage in the plutonic history of the region. This evidence does not support the ideas which have been put forward that volcanic activity is a relatively superficial phenomenon in the earth's crust; even though the subsidences themselves seem to belong to the upper, more or less brittle, layers.

Dr. Wilson then went on to say that he was not altogether convinced that the roughly concentric arrangement of the different granites within the Rosses complex was entirely due to cauldron-subsidence. He would have preferred to have had more concrete evidence of a central collapse than was apparently presented by the field exposures. Ring-structures—perhaps cylindrical-structures would be a better term, as it includes the third dimension—may result from types of intrusion other than subsidence. He referred here to the mode of intrusion in which many alkaline complexes occur (H. G. Backlund: 'On the mode of intrusion of deep-seated alkaline bodies'. *Bull. Geol. Inst. Upsala*, **24**, 1932). These commonly show on the surface as ring-structures, but they were formed by the continued, or periodic, upward movement of a central. relatively fluid, core through a less mobile cylindrical envelope, which, in turn, was surrounded by the country-rocks.

That the outer granite of the Rosses (G1A) rose along a ring-fracture resulting from the subsidence of a block of the migmatic granodiorite seems reasonably probable. Xenolithic blocks of the country-rock at the inner margin of the granite G1A suggest that this is so. It also seems reasonable to consider that G1, which forms the main cylindrical envelope of the complex, rose around the sinking block and, as far as can be seen, engulfed it completely—*es war spurlos versenkt*. Within the granites G2, G3, G4 there are no remnants of sunken masses derived from overlying or surrounding rocks, and the very absence of such fragments argues against such blocks having ever existed: rather it would be simpler if the later granites were considered to have been emplaced by piercement, uprising through the unconsolidated core of the earlier surrounding granite, or by periodic upward pulsations of the still mobile magma of that core. At the same time the shapes of the successive intrusions would be guided by the directions of weakness due to the joints developed in the consolidated peripheral granites. The speaker enquired whether there was any evidence against such a theory.

Whatever hypothesis one might choose for the mode of emplacement of the granites, their polygonal outline and its relationship to the jointing cannot be disputed. This is of particular interest because a somewhat similar connection was found by Dr. N. R. Martin around the margin of the Flamanville Granite. These two examples of the interdependence of magmatic intrusion and jointing, force one to the conclusion that the time interval between intrusion and fracturing must have been exceedingly short. In both complexes the jointing controlled the forms of embayments in the granite-margin as well as the shapes of xenoliths. The stoping of the country-rock followed the joint-pattern. At Flamanville, however, this pattern was directly related to the forces exerted by the granite-magma; and the jointing died away from the intrusion. The jointing in the Rosses is considered by Dr. Pitcher to have had an external origin. Dr. Wilson therefore asked the author whether he had found the joint-pattern to persist into regions remote from the ring-complex, which could be considered outside its possible sphere of influence.

DR. J. SUTTON congratulated the author on the skill with which he had established, so convincingly, a sequence of events in what might seem at first sight an uninteresting granite-mass.

The demonstration that a joint-system had been established in the country-rock early enough to control the emplacement of the first granite of the complex, and that this joint-system was essentially similar to those developed in the later members of the complex, opened up great possibilities. Could Dr. Pitcher and his colleagues extract from their mass of field evidence a picture of the joint-pattern in the country around the complex? If so, how did the structures, symmetrically arranged about a point north of Dungloe (the radial dykes and the steep outward-dipping granite-margins), fit in to the regional joint-pattern? Were the joints over a wide area of country-rocks produced by the forces which gave rise to the structures localised in the Rosses Granites, or did these granites take advantage of pre-existing lines of weakness already established throughout the region? The evidence presented suggested the first alternative was the more probable. It might, the speaker thought, turn out that the ring-complexes were simply the foci of crustal disturbances whose affects could be followed for many miles out into the country. One might anticipate that, in some part of Donegal, the joint-pattern, when carefully mapped, would reveal an underlying ring-complex whose igneous rocks were still covered. Whether this was so or not, the speaker hoped that eventually a map showing the arrangement of joints around the roughly north to south line of granite-masses, of which the Rosses complex was one, would be presented; such a map might point to further granites and might make clearer the modes of intrusion of those already known.

DR. E. H. T. WHITTEN referred to the fabric of the Rosses Granite, and asked if the felspars and biotites showed preferred orientation in the field, and, if so, what the relationship to the schlieren was. Dr. Pitcher seemed to imply that the latter possess a linear tangential pattern. Since such schlieren were usually considered to be streaked out by flow, Dr. Whitten asked how this fabric was reconciled with the concept of vertical magmatic movement. He also stated that for seventeen miles to the north his mapping had shown a joint-pattern similar to that of the Rosses area. Immediately north of the Rosses the joints appear to be parallel to, or normal to, the planar structure, and thus to simulate normal contraction-joints. The present paper (and other evidence) suggested that this sort of relationship of the jointing to the fabric did not in fact obtain throughout the area. The jointing to the north in Gweedore appeared to be later than a NE.–SW. shearing affecting the fabric of the 'country-rock' granodiorite, which must imply that the jointing is relatively late. Dr. Whitten asked if Dr. Pitcher considered there was or had been any jointing due to contraction, and, if not, what was the cause of the jointing?

DR. MAURICE WELLS congratulated the author on the interesting results obtained from his study of this ring-complex, and on the clear way in which these had been presented. In some of the Scottish gabbro ring-dykes where the contacts are sufficiently well exposed, their angular character suggested that they may have been controlled in detail by the joint-patterns of the surrounding rocks. It would be interesting to know whether the conditions which led to the development of a joint-system between each act of intrusion in the Rosses granites had also produced contact metamorphism and marginal chilling.

Finally, the speaker wanted to ally himself with Professor Read in regarding a uniform granitic texture, taken by itself, as a rather unsafe criterion of magmatic origin. In many gabbros of magmatic origin the texture was markedly heterogeneous. The uniformity seen in many granites may arise from the long period of crystallisation and recrystallisation involved, regardless of whether it takes place under essentially metamorphic or magmatic conditions. Of course, in the case of The Rosses granites the field-relations and composition of the successive intrusions proved their magmatic origin beyond doubt, independently of texture.

DR. PITCHER, in reply, thanked the members of the Association for their cordial reception of the paper.

The author agreed with Professor Read that the granites of NW. Donegal demonstrated the various modes of granite-emplacement. It was difficult to be certain of the origin of the schlieren in the late granites of the Rosses, for clear transitions from country-rock material did not exist. The author had been impressed with just such evidence in the migmatitic granodiorite, which was crowded with identical xenolithic material, and he was disposed to regard many of the schlieren within the granites as of 'accidental' origin. Dr. Pitcher emphasised that uniformity of mode and grain-size was part of a chain of evidence for the magmatic origin of the granites and was to be considered along with the nature of the contacts and the associated sheet-like intrusions. He was still of the opinion, however, that a migmatite would not be completely homogenised whilst still at the level of its formation.

In reply to Dr. Wilson, the speaker stated that, within the Rosses, the granites were clearly cross-cutting and the country-rocks had not been pushed aside. The latter had been removed upward or downward, either piecemeal or in the form of a large block. Fragments of the country-rocks were absent in the central granites, possibly because a general disruption had not occurred; on the other hand, the linear and outward-dipping contacts were indicative of the clean separation of a subsiding central block.

Dr. Pitcher agreed that comparison could be made with the Flamanville Granite if this were limited to the interdependence of emplacement and jointing. In reply to both Dr. Wilson and Dr. Sutton the author stated that in the Rosses the joint-pattern was not as directly related to forces exerted during emplacement as was so clearly the case at Flamanville. Dr. Whitten had confirmed that the joint-pattern of the Rosses was continued many miles northward into Gweedore and reference to Dr. Gindy's thesis showed that it continued equally far to the south. The author had used the term 'regional' to emphasise this extension outside the immediate confines of the Rosses. Though he was also of the opinion that the most prominent joint-system was structually connected with granite-emplacement yet he did not think that this widespread system was merely centred on the Rosses Ring Complex.

Replying to Dr. Whitten, the author said that the biotites of the outer granite G1 showed a faint alignment in the field which was parallel to the elongation of the xenolithic elements. Though difficult to measure on glaciated surfaces, the vertical dimension of these elements did not seem to be consistently less than the maximum horizontal dimension. The only certain feature was that, in xenolithic material with a platy form, the flat surface was often parallel to the contact-plane; this was consistent with flow parallel to the contact, but yielded no evidence of direction. In this connection the author recalled that Ogden Tweto (*Bull. Geol. Soc. Amer.*, 1951) had demonstrated that the direction of orientation of linear elements in the Pando Sills depended on the proximity to the contact. Dr. Pitcher added that, in the Rosses, the joints were not directly related to the fabric of the country-rock. In due course the joints might be found to have been intimately connected with granite tectonics.

Dr. Pitcher thanked Dr. M. Wells for his remarks and in reply said that marginal chilling was not a marked feature of the ring-granites; finer grained margins did exist but a narrow pegmatitic fringe was more frequently present and, in a few cases, a fine-grained selvage appeared to be in the process of resorbtion. Contact-effects were not noticed in the granodioritic country-rocks or in the various granites, but the pegmatitic dykes connected with the early microgranite sheets were sheathed with skarn when traversing the marbles and the sillimanite of the pelitic rafts was extensively replaced by shimmer aggregates of white mica.

FORAMINIFERA FROM THE UPPER OXFORD CLAY (JURASSIC) OF REDCLIFF POINT, NEAR WEYMOUTH, ENGLAND

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ABSTRACT.—The systematic descriptions of twenty-three species of Foraminifera, of which four are new, are presented. The present paper is the first description of a foraminiferal fauna from the Oxford Clay of Dorset.

1. INTRODUCTION

IN 1937 Mr. C. D. Ovey systematically collected twenty-five samples at two-foot intervals from the Upper Oxford Clay at Redcliff, Dorset. The microfauna was separated from the residues of these samples, and the present paper is a study of the Foraminifera.[1]

Little work has been published on Jurassic microfauna from Britain, and only very brief lists of Foraminifera from the Oxford Clay. Nothing has been published since 1886 on British Oxford Clay foraminiferal faunas. Towards the end of the nineteenth century, papers by Gümbel (1862), Schwager (1865) and Deecke (1884, 1886) were published on the Foraminifera from the Oxford Clay of Europe; little has appeared since (see Barnard, 1952, p. 337).

2. STRATIGRAPHICAL DETAILS OF THE SECTION

All the samples were collected from the upfaulted block of Oxford Clay occurring at Redcliff Point. According to Arkell (1947, p. 34), about 80 ft. of the *cordatum* Zone clays are exposed in the upfaulted portion, the base of the zone being below sea level. Ovey, using the base of the cliff as his datum, systematically collected samples at approximate intervals of two feet, over a range of 0–52 ft. of the section. All the samples were, therefore, collected from the *cordatum* Zone. Except for a small gap, this section follows on that already described by the author from Warboys, Huntingdonshire (Barnard, 1952).

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[1] The material was collected with the aid of the Godman Exploration Fund. The figures prefixed by the initial letter P. indicate registered numbers in the Geological Collections of the British Museum (Natural History).

3. SYSTEMATIC DESCRIPTIONS OF THE FORAMINIFERA

Family: LITUOLIDAE

Genus: **AMMOBACULITES** Cushman, 1910

Ammobaculites suprajurassicum (Schwager)

Fig. A, 2 a, b

non 1846. *Spirolina agglutinans* d'Orbigny, p. 137, pl. vii, figs. 10–12.
1865. *Haplophragmium suprajurassicum* Schwager, p. 92, pl. ii, fig. 1.
1867. *Haplophragmium coprolithiforme* Schwager, p. 654, pl. xxxiv, fig. 3.
?1879. *Haplophragmium pictoncium* Berthelin, p. 26, pl. i, figs. 1, 2.
1886. *Haplophragmium coprolithiforme* Schwager; Deecke, p. 15, pl. ii, fig. 2 a–d.
1886. *Haplophragmium vetustum* Terquem & Berthelin; Deecke, p. 16, pl ii, fig. 1 a–e.
1922. *Haplophragmium coprolithiforme* Schwager; Paalzow, p. 31, pl. iv, fig. 3.
1935. *Haplophragmium agglutinans* (d'Orbigny); Macfadyen, p. 9, pl. i, fig. 1 a, b.
?1935. *Haplophragmium pictonicum* Berthelin; Macfadyen, p. 10, pl. i, fig. 2 a, b.

Material. P. 41450, 41451 (i–iii); horizon, 2–4 ft. above base of the cliff

Description. The abundant specimens of this species show considerable variation in size and shape of the test. The agglutinated test is composed of moderately large sand-grains, particles of quartz and mica, organic fragments, sponge spicules and occasionally the tests of other Foraminifera, such as *Lenticulina münsteri* (Roemer). The calcareous cement is colourless and sometimes shows signs of decomposition. The initial portion of the test is composed of between four to seven chambers planispirally arranged. This spire may be swollen or slightly compressed. In specimens which have swollen globose chambers the sutures are deeply sunken.

In the early growth-stage the aperture is slit-like and situated at the base of the apertural face. As further chambers are added the spire uncoils into a rectilinear or curvilinear series. The most abundant form has three or four drum-shaped chambers in the later portion of the test. These chambers show no tendency to overlap on to the spiral portion. The amount of constriction along the sutures between the chambers varies considerably. Another abundant variant with an uncoiling test is that in which the first chamber, following the initial spire, is broad and overlaps a large portion of it. Subsequently the chambers decrease in size so that the test tapers towards the aperture. As the growth of the test proceeds the position of the aperture changes from the base of the apertural face to central terminal.

Remarks. The Recent specimens described by d'Orbigny as *Spirolina agglutinans* appear to be very similar to these Oxford Clay forms; it was therefore decided to assign the forms described here to *Ammobaculites* *suprajurassicum* (Schwager). Specimens described by Macfadyen (1935) and preserved at the Sedgwick Museum, Cambridge, are similar.

Ammobaculites minuta sp. nov.

Fig. A, 3a, b, c

Material. *Holotype.* P. 41452 (i); horizon, 18–20 ft. above base of the cliff. *Topotypes.* P. 41452 (ii, iii).

Diagnosis. The relatively small test is compressed, and consists of a loosely coiled spire of about eight chambers, which uncoils into a curvilinear series of about three chambers. The wall is composed of an irregular mosaic of quartz-fragments cemented together by a milky-white calcareous cement. The constrictions at the sutures between the chambers are well marked in the uncoiled portion of the test. Aperture, terminal, central.

Genus: **HAPLOPHRAGMOIDES** Cushman, 1910

Haplophragmoides rotunda sp. nov.

Fig. A, 1 a, b

Material. *Holotype.* P. 41453; horizon, 14–16 ft. above base of the cliff.

Diagnosis. The small test consists of a spire of about eight chambers to the whorl. It is biconvex and nautiliform in cross-section. The shell is occasionally slightly helicoid. The wall contains much fine-grained agglutinated material cemented by a grey calcareous cement. The sutures at the chamber-junctions vary from flush with the surface and almost invisible to deeply constricted. Aperture, basal, slit-like.

Family: TROCHAMMINIDAE

Genus: **TROCHAMMINA** Parker and Jones, 1859

Trochammina sp.

Material. P. 41454; horizon, 18–20 ft. above base of the cliff.

Description. Small arenaceous test consisting of a compressed trochoid spire of two or three whorls of eight chambers. All chambers are visible from the dorsal side, only those of the last whorl being seen on the ventral side. Dorsal side slightly convex, ventral concave. The wall consists of fine-grained material with a large amount of grey calcareous cement. The periphery is lobulate, sutures sunken. Early chambers are circular, but later become crescentic. Aperture is an arched-slit at the inner margin of the ventral side.

Family: LAGENIDAE

Genus: **LENTICULINA** Lamarck, 1804

Lenticulina münsteri (Roemer)

Fig. A, 10

1839. *Robulina münsteri* Roemer, p. 48, pl. xx, fig. 29.
1952. *Lenticulina münsteri* (Roemer), Barnard, p. 339, fig. B, 5, *et syn.*

Material. P. 41455; most horizons.

Remarks. Specimens from Redcliff show wide variation in the size of the adult test.

Lenticulina flaccida (Schwager)

Fig. B, 5

1865. *Marginulina flaccida* Schwager, p. 116, pl. iv, fig. 27.
1952. *Lenticulina flaccida* Schwager; Barnard, p. 340, fig. B, 7, *et syn.*

Material. P. 41456; horizon, 34–36 ft. above base of the cliff.

Remarks. The sporadic specimens show little variation.

Genus: **PLANULARIA** Defrance, 1824

Planularia protracta (Bornemann)

Fig. A, 4

1854. *Cristellaria protracta* Bornemann, p. 39, pl. iv, fig. 27 a, b.
1952. *Planularia protracta* (Bornemann), Barnard, p. 343, fig. C a–d, *et syn.*

Material. P. 41457; horizon, 24–26 ft. above base of the cliff.

Remarks. The variation in the coiling of the test is similar to that already described by the author (1952, p. 345). Variation occurs in the thickness of the test, the latter tending in some specimens to become biconvex and approach an uncoiled lenticuline-like form.

Genus: **FRONDICULARIA** Defrance, 1824

Frondicularia franconica Gümbel

Fig. B, 2 a, b; 3 a, b

1862. *Frondicularia franconica* Gümbel, p. 219, pl. iii, fig. 13 a, b, c.
1952. *Frondicularia franconica* Gümbel; Barnard, p. 340, fig. A, 1, *et syn.*

Material. P. 41458 (i & ii); horizon, 30–32 ft. above base of the cliff.

Remarks. Some specimens show 'rejuvenation', the test being built in two distinctly differing stages. Variation in the shape of the end chamber, from circular to elongate, occurs together with differing amounts of constrictions at the sutures. There is also a wide range in size.

Genus: **LINGULINA** d'Orbigny, 1826

Lingulina cf. **laevissima** (Terquem)

Fig. B, 8 a, b

cf. 1866. *Frondicularia laevissima* Terquem, p. 481, pl xix, figs 19 a, b.
cf. 1870. *Frondicularia longiscata* Terquem, p. 216, pl. xxii, figs. 23, 24.
1952. *Lingulina* cf. *laevissima* (Terquem); Barnard, p. 347, fig. A, 3, *et syn.*

Material. P. 41459; horizon, 20–22 ft. above base of the cliff.

Remarks. These specimens show little variation, and are very similar to

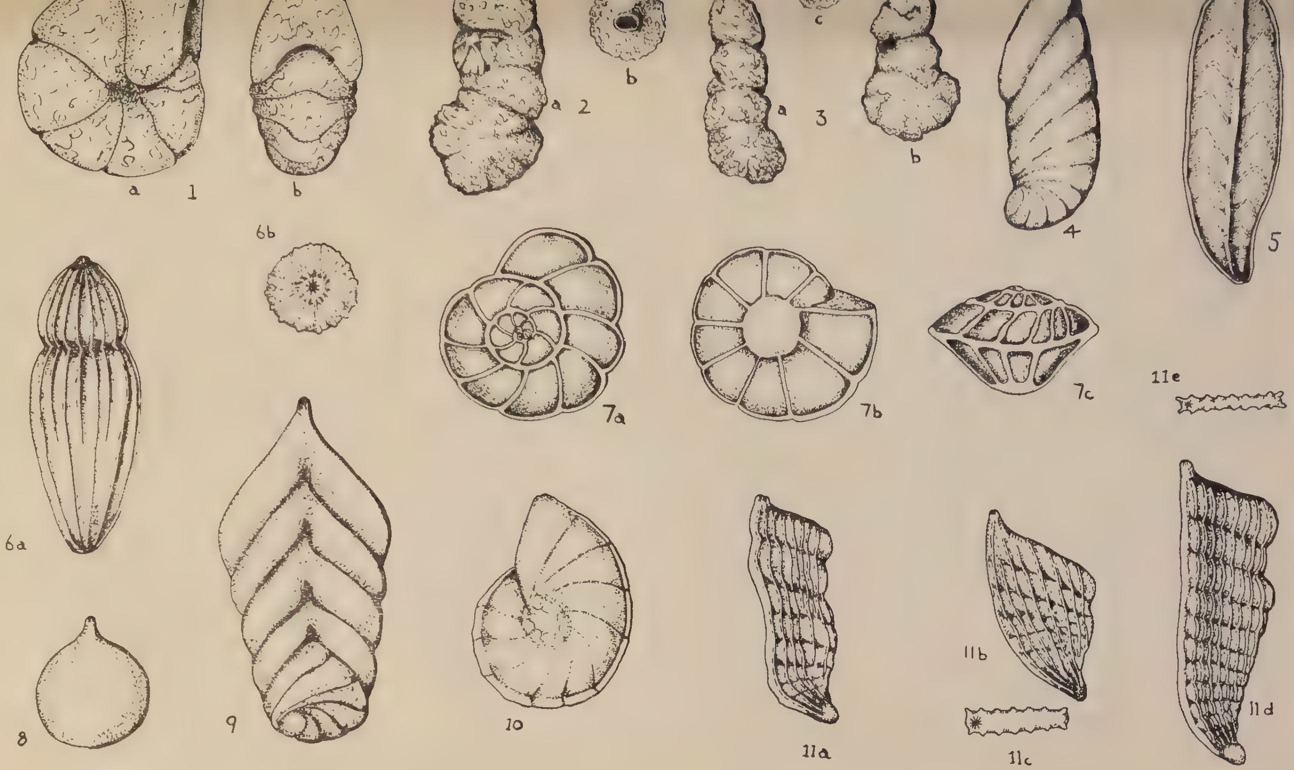

Fig. A. Upper Oxford Clay Foraminifera from Redcliff Point, Dorset those described by Terquem as *Frondicularia longiscata* from the *parkinsoni* Zone.

Genus: **LAGENA** Walker and Jacob, 1798

Lagena sp.

Fig. A, 8

Material. P. 41462; horizon, 18–20 ft. above base of the cliff.

Description. The unilocular, almost spherical test, is finely perforate and smooth. The small radiate aperture occurs on a small drawn-out apertural neck.

Genus: **DENTALINA** d'Orbigny, 1826

Dentalina gümbeli Schwager

Fig. B, 6

1865. *Dentalina Gümbeli* Schwager, p. 101, pl. ii, fig. 20.
1952. *Dentalina gümbeli* Schwager; Barnard, p. 346, fig. A, 7, *et syn.*

Material. P. 41463; horizon, 0–2 ft. above base of the cliff.

Remarks. The smooth *Dentalinae* from Redcliff show considerable variation in the size of the test and in the shape and arrangement of the chambers. It is almost impossible to assign them to a species, so wide are the differences between individuals, the whole group representing a very 'plastic' stock.

Genus: **NODOSARIA** Lamarck, 1812

Nodosaria sp.

Material. P. 41464; horizon, 0–2 ft. above base of the cliff.

Description. One internal cast was found with remnants of the test still remaining. The test consists of eight chambers which increase slowly in size and finally become elongate. The sutures are deeply constricted, and, in the depressions, remnants of the ornament, consisting of about eighteen fine longitudinal costae, remain. Aperture broken.

Genus: **VAGINULINA** d'Orbigny, 1826

Vaginulina sp.

Fig. B, 7

cf. 1868. *Marginulina contracta* Terquem, p. 125, pl. viii, fig. 18, 21, 24 only (*non* Costa).

Material. P. 41465; horizon, 18–20 ft. above base of the cliff.

Description. The slightly arcuate test consists of about eight chambers. The globular proloculum is apiculate, with the initial spine sometimes preserved. The initial stages of the test are straight, parallel-sided, but later become concavo-convex. The initial end is a loose coil with strongly oblique sutures, flush with the surface of the test, later becoming constricted, but remaining oblique. Final chambers are inflated. The surface of the test is smooth. The radiate aperture is peripheral on an elongate neck.

Genus: **PSEUDOGLANDULINA** Cushman, 1929

Pseudoglandulina oveyi sp. nov.

Fig. A, 6 a, b

Material. *Holotype.* P. 41461; horizon, 18–20 ft. above base of the cliff.

Diagnosis. Pupiform test, consisting of about six drum-shaped chambers forming a rectilinear series. Initially the sutures are flush, later slight constrictions occur. The ornament consists of strong longitudinal costations. On the first two or three chambers there are eight to ten equally spaced vertical ribs, later further ribs are developed in the spaces between the earlier set. The new costations are originally fine and only slightly raised above the surface of the test, but after about one chamber they have developed as strongly as the earlier costae. All the ribs decrease and finally become obsolete on the end-chamber. Aperture is central, terminal, radiate.

Remarks. Superficially these specimens resemble *Pseudoglandulina multicostata* (Bornemann) but the ribs in this species extend from the initial end.

Little variation occurs in the shape of the end-chamber which occasionally becomes elongate. Some specimens have a slow growth-rate and superficially resemble a nodosarine growth. One abnormally large specimen was arcuate.

Genus: **NEOFLABELLINA** Bartenstein, 1948

Neoflabellina semi-involuta (Terquem)

Fig. A, 9

1870. *Flabellina semi-involuta* Terquem, p. 223, pl. xxiii, fig. 29 only, and pl. xxiv, figs. 1–3 only.

Material. P. 41466; horizon, 20–22 ft. above base of the cliff.

Description. The small test is greatly compressed, so that even from the initial portion it is parallel-sided. The proloculum is followed by about six curved triangular chambers forming a loose coil. The chambers are involute, and, as later chambers are added, involution increases. Finally, a rectilinear portion of three to six chevron-shaped chambers is added. There is little or no overlap of these chambers on to the early portion, and this, together with a stable growth-rate, produces a parallel-sided test. Initially the radiate aperture is peripheral, later changing abruptly to a central terminal position.

Remarks. The initial portion of the test is similar to *Planularia pauperata* Jones & Parker, a species common in the Lias.

Genus: **SARACENELLA** Franke, 1936

Saracenella triquetra (Gümbel)

Fig. B, 4 a, b

1862 *Cristellaria triquetra* Gümbel, p. 225, pl. iii, fig. 28 a, b.
1952. *Saracenella triquetra* (Gümbel), Barnard, p. 343, fig. B, 2, *et syn.*

Material. P. 41467; horizon, 48–50 ft. above base of the cliff.

Remarks. There is nothing to add to earlier descriptions.

Genus: **TRISTIX** Macfadyen, 1941

Tristix triangularis sp. nov.

Fig. A, 5

Material. *Holotype.* P. 41468; horizon, 2–4 ft. above base of the cliff.

Diagnosis. Test consists of a rectilinear series of about four to eight chambers. A small globular proloculum is followed by chambers which are distinctly triangular in cross-section. Sometimes the initial end of the test is slightly arcuate. The chambers are separated by slightly depressed sutures, which are distinctly arched upwards towards the aperture, so that, on each of the surfaces of the triangular test, the chambers appear frondicularine. The edges of the test are sharp and narrow; keel-like flanges of nearly equal width run longitudinally along them.

The end chamber is drawn out, pyramidal, and tapers into a long cylindrical apertural chamberlet, with a central, terminal, radiate aperture.

Genus: **CITHARINA** d'Orbigny, 1839

Citharina cf. **serratocostata** (Gümbel)

Fig. A, 11 a–e

cf. 1862. *Marginulina serratocostata* Gümbel, p. 222, pl. iii, fig. 23 a, b.
cf. 1862. *Marginulina flabellata* Gümbel, p. 223, pl. iii, fig. 24 a–c.
?cf. 1888. *Vaginulina* cf. *flabelloides* Terquem; Deecke, p. 29, pl i, fig. 16.
?cf. 1888. *Vaginulina kinklistheisa* Deecke, p. 32, pl. i, fig. 18, 18 a.
cf. 1888. *Marginulina* cf. *orthonota* Reuss; Deecke, p. 35, pl. i, fig. 17, 17 a.

Material. P. 41469 (i, ii, iii); horizon, 46–48 ft. above the base of the cliff.

Description. Test triangular, compressed, ranging considerably in shape and size; usually, however, the angle at the proloculum is less than 40°. The proloculum is either globular, elevated above the general level of earlier chambers, or compressed and flush with the surface. The test is composed of about ten narrow, almost parallel-sided, chambers. The sutures between these chambers are either deeply set, so as to be almost entirely obscured by ornament, or constricted producing a lobulate internal margin.

The radiate, marginal aperture is situated on a smooth apertural face, varying in shape from triangular to rectangular.

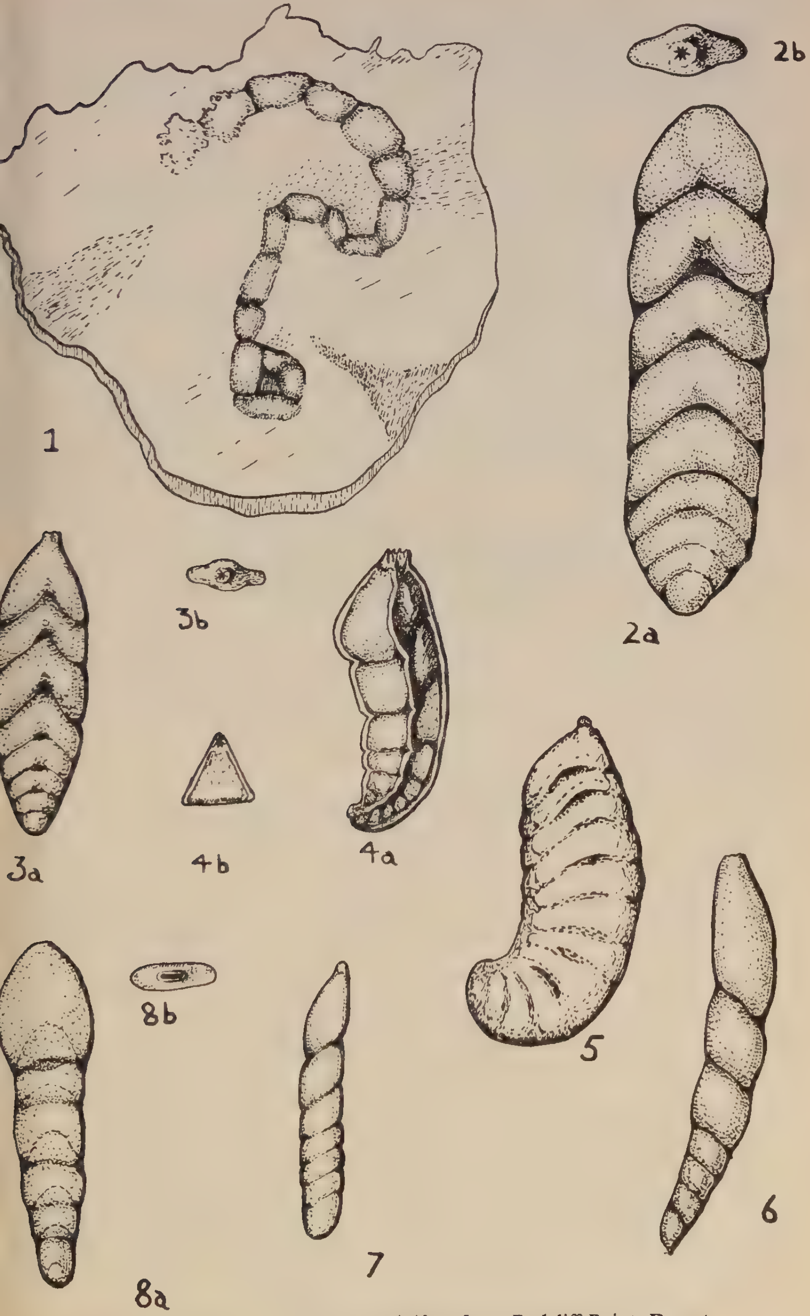

Fig. B. Upper Oxford Clay Foraminifera from Redcliff Point, Dorset

The ornament consists of moderately coarse to very fine longitudinal costae which bend inwards at the sutures, and are uninterrupted.

Considerable variation occurs in the number and arrangement of the ribs.

The chief variations in ornament are:

(1) A constant number (about ten) costae begin at the proloculum and continue the whole length of the test. In a few individuals the ribs become obsolete on the last chamber.

(2) Four main costations are confined closely parallel to the apertural margin of the test. These continue for the whole length of the shell. Two or three further parallel ribs are added at about the third chamber, continuing to the end chamber.

Variants of the latter (2) may be grouped as follows:

(2a) Further small, finer ribs are intercalated between all earlier ribs in later chambers.

(2b) Fine ribs are intercalated between those occurring in the non-apertural side of the test.

Family: POLYMORPHINIDAE

Genus: **BULLOPORA** Quenstedt, 1856

Bullopora rostrata Quenstedt

1858. *Bullopora rostrata* Quenstedt, p. 580, fig. 8.
1952. *Bullopora rostrata* Quenstedt; Barnard, p. 348, fig. B, 8.

Material. P. 41472; throughout Redcliff Point section.

Remarks. As in all the Oxford Clay this form occurs abundantly attached to oyster-shells.

Genus: **POLYMORPHINA** d'Orbigny, 1826

Polymorphina jurassica (Gümbel)

1862. *Guttulina jurassica* Gümbel, p. 228, pl. 4, fig. 15 a, b.
1952. *Polymorphina jurassica* (Gümbel), Barnard, p. 348, fig. B, 3, *et syn.*

Material. P. 41460; horizon, 24–26 ft. above base of the cliff.

Remarks. There is nothing new to add to earlier descriptions.

Family: ROTALIDAE

Genus: **SPIRILLINA**

Spirillina tenuissima Gümbel

1862. *Spirillina tenuissima* Gümbel, p. 214, pl. iv, fig. 12 a, b.

Material. P. 41471; horizon, 18–20 ft. above base of the cliff.

Description. A small circular test, consisting of a minute globular proloculum followed by a tube of about nine whorls, slowly increasing in diameter. Only the last three whorls are distinctly visible. The coil is evolute, with a wide open, shallow umbilicus on both sides of the test. Slight variation occurs in the coiling, from a planispire to a form slightly more umbilicate on one side. The tests were usually replaced by iron pyrites, but occasionally were of vitreous porous calcite.

Genus: **EPISTOMINA** Terquem, 1883

Epistomina cf. **elegans** (d'Orbigny)

Fig. A, 7 a–c

cf. 1826. *Rotalia* (*Turbinulina*) *elegans* d'Orbigny, p. 276, No. 54.
?1860. *Rotalia elegans* d'Orbigny; Jones and Parker, pl. xx, fig. 46.
1935. *Epistomina elegans* (d'Orbigny), Macfadyen, p. 16, pl. 1, figs. 20 a–c.

Material. P. 41470; horizon, 28–30 ft. above the base of the cliff.

Description. Test strongly biconvex, consisting of about three whorls of eight chambers to each whorl, visible on the dorsal side, only the last whorl is visible on the ventral side. The globular proloculum and chambers are separated by limbate sutures. On the ventral side a large central boss is visible, but it is not seen on the dorsal side.

Remarks. The preservation of the specimens does not allow close comparison with those described by Terquem and Macfadyen. It is possible that many of the species described by Terquem should belong here as variants of a single species.

The author does not feel justified in creating a new species for this form. As more knowledge on the distribution of the Jurassic Epistomininae becomes available, species of importance stratigraphically may appear.

Family: OPHTHALMIDIIDAE

Genus: **NUBECULINELLA** Cushman, 1930

Nubeculinella bigoti Cushman

Fig. A, 1

1930. *Nubeculinella bigoti* Cushman, p. 134, pl. 4, figs. 2–3.

Material. P. 41473; horizon, 12–14 ft. above base of the the cliff.

Description. The adherent test consists of an initial coil composed of a globular proloculum, with a small tube planispirally wound round it, followed by a loose coil of three or four chambers. This spine uncoils and a meandrine series of hemi-elliptical chambers (6–16) are added. The apertures have not been observed due to bad preservation.

Remarks. Cushman's (1930) species was obtained from beds of the same age as those studied at Redcliff Point, and is probably the same form. There is always some doubt, however, in the correct identification of Jurassic adherent Foraminifera because of changes which have subsequently taken place in the wall-structure.

Table I. DISTRIBUTION OF FORAMINIFERAL SPECIES IN THE OXFORD CLAY (*Cordatum* Zone), REDCLIFF POINT, DORSET

	2'-0'	4'-2'	6'-4'	8'-6'	10'-8'	12'-10'	14'-12'	18'-16'	20'-18'	22'-20'	24'-22'	26'-24'	28'-26'	30'-28'	32'-30'	34'-32'	36'-34'	38'-36'	40'-38'	42'-40'	44'-42'	46'-44'	48'-46'	50'-48'	52'-50'
1 Ammobaculites suprajurassicum (Schwager)	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2 Lenticulina münsteri (Roemer)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3 Frondicularia franconica Gümbel	X		X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X				X	X
4 Citharina cf. serratocostata (Gümbel)	X	X	X	X	X	X		X								X		X	X	X			X	X	X
5 Dentalina gümbeli Schwager	X	X		X			X		X	X	X					X								X	X
6 Nodosaria sp.	X								X ?																
7 Planularia protracta (Bornemann)	X		X	X			X			X		X												X	
8 Bullopora rostrata Quenstedt		X	X	X			X		X	X	X	X						X	X					X	X
9 Tristix triangularis sp. nov.		X			X	X						X										X			
10 Lingulina cf. laevissima (Terquem)		X				X			X	X	X													X	
11 Lenticulina flaccida (Schwager)		X	X			X	X		X	X	X	X	X		X	X	X		X	X				X	
12 Polymorphina jurassica (Gümbel)			X						X			X												X	X
13 Trochammina sp.			X						X	X		X											X		
14 Vaginulina sp					X																			X	
15 Nubeculinella bigoti Cushman						X	X																X		
16 Haplophragmoides rotunda sp. nov.								X							X										X
17 Ammobaculites minuta sp. nov.									X						X										
18 Lagena sp.									X																
19 Epistomina cf. elegans (d'Orbigny)									X		X	X		X	X			X		X	X			X	X
20 Pseudoglandulina oveyi sp. nov.									X																
21 Spirillina tenuissima Gümbel									X																
22 Neoflabellina semi-involuta (Terquem)										X															
23 Saracenella triquetra (Gümbel)										X														X	

CONCLUSIONS

Foraminifera were found in all the samples, but considerable variation occurred in their relative abundance. The bulk of the fauna generally consisted of *Ammobaculites suprajurassicum* (Schwager) and *Lenticulina münsteri* (Roemer). Most other species are of sporadic occurrence and often rare, except *Frondicularia franconica* Gümbel, *Citharina* cf. *serratocostata* (Gümbel), *Bullopora rostrata* Quenstedt, *Lenticulina flaccida* (Schwager) and *Epistomina* cf. *elegans* (d'Orbigny) which occur in these samples as long-range forms. Foraminifera are abundant from 0–10 ft., then, until 16 ft., become rare and small. Diminutive forms are common from 16–22 ft., and then the same species are represented from 22–26 ft. by large specimens. These differences are probably due to changes in environment and not to sorting, because other microfauna (ostracods) are the same size, in spite of changes in the size of the Foraminifera. Foraminifera were rare in the sample 26–28 ft. The maximum abundance of forms occur from 28–38 ft. and a minimum from 38–44 ft.; gradually the Foraminifera become abundant again from 44–52 ft. The fluctuations in abundance and size bear no relationship to the composition of the residues.

Certain differences in the occurrence and distribution of the Foraminifera are apparent between those from the *lamberti* and lower *cordatum* Zones of Warboys and the upper *cordatum* Zone of Redcliff Point. Some of these differences are due to environmental changes—facies faunas—but others may prove to be of stratigraphical use in dating the beds.

Among the commonly occurring species present at Warboys, but absent at Redcliff Point, are *Lenticulina quenstedti* (Gümbel) and *Frondicularia pseudosulcata* Barnard. The absence of the former is of interest for this species is present in most Middle and Upper Jurassic Beds, the latter, however, may have its upper limits of distribution confined to lower *cordatum* times.

The paucity of—indeed, almost complete absence of—*Ammobaculites suprajurassicum* (Schwager) from the lower zones at Warboys and also Stewartby, may be significant stratigraphically although species of this genus are often facies forms. New forms common at Redcliff Point are *Citharina* cf. *serratocostata* (Gümbel) and *Epistomina* cf. *elegans* (d'Orbigny); the latter—absent at Warboys—are, however, present in still lower zones explored at Stewartby, and are usually considered as facies fossils in the Jurassic.

Amongst the less common species, with a more sporadic distribution in each section, are *Tristix triangularis* Barnard (present at Redcliff Point) and *Vaginulina harpa* Roemer (present at Warboys). Other rarer forms, although confined to certain levels, occur sporadically and appear at present to be of little stratigraphical value.

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EXPLANATION OF FIGURES

FIG. A

1. *Haplophragmoides rotunda* sp. nov.
   a. Side view. b. Apertural view. × 25 P. 41453.
   14–16 ft. above base of cliff.
2. *Ammobaculites suprajurassicum* (Schwager).
   a. Side view showing incorporation of a specimen of *Lenticulina münsteri*
   (Roemer) in the wall. b. Apertural view. × 25 P. 41450.
   2–4 ft. above base of cliff.
3. *Ammobaculites minuta* sp. nov.
   Holotype. a. Side view. c. Apertural view. × 40 P. 41451 (i).
   b. Topotype × 40 P. 41452 (ii).
   18–20 ft. above base of cliff.
4. *Planularia protracta* (Bornemann). × 40 P. 41457.
   24–26 ft. above base of cliff.
5. *Tristix triangularis* sp. nov. Holotype. × 40 P. 41468.
   2–4 ft. above base of cliff.
6. *Pseudoglandulina oveyi* sp. nov. Holotype. × 40 P. 41461.
   18–20 ft. above base of cliff.
7. *Epistomina* cf. *elegans* (d'Orbigny).
   a. Dorsal view. b. Ventral view. c. Side view. × 40 P. 41470.
   28–30 ft. above base of cliff.
8. *Lagena* sp. × 100 P. 41462.
   18–20 ft. above base of cliff.
9. *Neoflabellina semi-involuta* (Terquem). ×40 P. 41466.
   20–22 ft. above base of cliff.
10. *Lenticulina münsteri* (Roemer). × 30 P. 41455.
    10–12 ft. above base of cliff.
11. *Citharina* cf. *serratocostata* (Gümbel).
    a, b, d. Side views showing difference in ornament.
    c, e. Apertural. ×40 P. 41469 (i, ii, iii).
    46–48 ft. above base of cliff.

FIG. B

1. *Nubeculinella bigoti* Cushman. × 45 P. 41473.
   12–14 ft. above base of cliff.
2. *Frondicularia franconica* Gümbel.
   a. Side view. b. Apertural view. × 90 P. 41458 (i).
   30–32 ft. above base of cliff.
3. *Frondicularia franconica* (Gümbel).
   a. Side view. b. Apertural view. × 90 P. 41458 (ii).
   30–32 ft. above base of cliff.
4. *Saracenella triquetra* (Gümbel).
   a. Side view. b. Apertural view. × 60 P. 41467.
   48–50 ft. above base of cliff.
5. *Lenticulina flaccida* (Schwager). × 60 P. 41456.
   34–36 ft. above base of cliff.
6. *Dentalina gümbeli* (Schwager). × 60 P. 41463.
   0–2 ft. above base of cliff.

7. *Vaginulina* sp. × 60 P. 41465.
   18–20 ft. above base of cliff.
8. *Lingulina* cf. *laevissima* (Terquem).
   a. Side view. b. Apertural view. × 60 P. 41459.
   20–22 ft. above base of cliff.

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THE GLACIAL CHRONOLOGY OF PART OF THE MIDDLE TRENT BASIN

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SUMMARY.—The glacial chronology of that part of the River Trent Basin lying between Rugeley and Long Eaton is described in outline following detailed work on the morphology of the area. A succession of boulder clays and glacial gravels may be linked with well-preserved river terraces to give an unbroken sequence that agrees quite closely with that already established in the West Midlands. Some earlier correlations of the Younger terraces of the Trent and the Severn–Avon are re-examined and a revised dating suggested for the lowest terraces of the Trent. The evidence from this part of the Trent Basin is summarised in tabular form together with that already established for the Rivers Severn, Avon and Thames.

1. INTRODUCTION

THE river-terraces and the associated glacial drift-deposits of the Trent Basin show no greater complexities than those of the Severn, yet they have so far been inadequately described. In the course of morphological work on the Trent Basin between Long Eaton and Rugeley, the river-terraces and drift-deposits were mapped by the author, while the Geological Survey have kindly allowed access to the newly-surveyed 6-inch field sheets covering Sheet 40 (Burton-on-Trent). With the aid of this new information, an outline chronology may be built up by following the broad arguments used by Professor Wills (1937) in his 'Pleistocene History of the West Midlands'. The chronology follows that generally accepted for the boulder clays, but a revised dating is suggested for the various river-terraces. The fluvio-glacial gravels mapped by the Geological Survey (Fox-Strangeways, 1905) at about 90 ft. above alluvium are believed to be the remnants of a true river-terrace.

2. TERMINOLOGY

In any account of Pleistocene Chronology there arises the question of correlation. The sequence proposed here has not the authority of an independent chronology, and consequently the deposits and events will be referred to by the nomenclature put forward by Arkell (1943). This avoids any question of correlation with areas outside Great Britain, yet allows of general correlation with other areas of Southern England. The terms refer to time only, and are consequently of more value than the names of particular ice-sheets as in this area several distinct ice-sheets appear to have been contemporaneous.

3. PREVIOUS WORK

A very early account of the drifts by R. M. Deeley (1886) recognised the fundamental division into Chalky and Pennine Boulder Clays, but, as Deeley himself later realised (1914, p. 72), these are not necessarily of different ages. The Pennine Boulder Clay is characterised by Carboniferous erratics, but as the so-called Chalky Boulder Clay contains only flints west of Nottingham, it seems best to follow Professor Swinnerton in calling it Eastern Drift. The invasion by ice-sheets moving in different directions led Dr. Bernard Smith to describe the Middle Trent Valley as ‘a cockpit, where tongues of ice from various directions strove successively for territorial rights’ (quoted by Swinnerton, 1937a, p. 55).

The river-terraces (including the fluvio-glacial gravels of the Geological Survey) all contain flints (Fox-Strangeways, 1905) and consequently must be later in age than the Eastern Drift. Professor Swinnerton (1937b) followed the Geological Survey in ignoring the fluvio-glacial gravels, and recognised the Older and the Younger Gravels as the only two river-terraces. The Older Gravels form the main terrace of the Trent with a maximum height of some 20–30 ft. above alluvium, while the Younger Gravels lie beneath the present floodplain. These gravels have yielded a few flint artefacts and on this evidence were assigned to the Main Interglacial and Third Interglacial periods respectively (Swinnerton, 1937b, p. 7). Later work by A. L. Armstrong (1939) on large numbers of quartzite implements appeared to confirm this, but the implements are crude and it seems unlikely that archaeological evidence alone can give a satisfactory dating.

4. THE CHRONOLOGY

Any chronology of this area must rest on the dating of the extensive, though greatly dissected, sheet of boulder clay; divisible by its erratic content into Pennine and Eastern components. The subsequent dissection of this extensive sheet of boulder clay is about 150 ft., and Professor Wills (1937, p. 88) has shown that in the West Midlands a similar degree of dissection characterises the outwash-gravels of his widespread Older Drift. It is impossible to give a more precise dating by any direct method, but, on analogy with the West Midlands, this widespread sheet of drift appears to be of Catuvellaunian age; that is, contemporary with the Main Eastern and Second Welsh Glaciations. The Eastern Drift swept far westwards across Needwood Forest, as in the Avon Basin, where a similar incursion of Eastern Drift occurred in the Catuvellaunian Glaciation (Tomlinson, 1935). The subsequent dissection of the Eastern Drift of the Avon Basin is also about 150 ft. and the outwash-gravel (No. 5 terrace) may be traced down the Avon at some 140–50 ft. above the present valley-floor (Tomlinson, 1935, p. 459). An independent check is provided by the correlation suggested by Fox-Strangeways (1903, p. 43) between the Eastern Drift of the Trent Valley and the Chalky Boulder Clay of the Leicester District which is generally regarded as of Catuvellaunian age.

It is not possible to achieve a more rigorous dating of these boulder clays, and consequently the suggested Catuvellaunian age is to be regarded at this stage as a working hypothesis. The chronology to be established on this dating appears to agree with neighbouring areas and, because of the limitations of the evidence, it is on the complete sequence that any test of its validity must depend.

There appear to be very few deposits surviving from before this extensive Catuvellaunian Glaciation. In the Birmingham plateau, Professor Wills (1937, p. 81) found high-level deposits lying up to 300 ft. above neighbouring valley-floors, and believed these to have survived from the Berrocian Glaciation. It is suggested that comparable drifts occur in the Middle Trent Basin. The most impressive example is the lens-shaped deposit of fluvio-glacial gravel at Blackwall, north-west of Derby. This forms the summit of a narrow ridge with the base of the gravel lying some 260–350 ft. above the adjacent valley-floors (Green, 1887, p. 91). These gravels probably represent a stage in the 'retreat' of the Pennine Glacier as there is evidence that pre-Main Eastern (Catuvellaunian) drifts extend to the south (Tomlinson, 1935). No deposits appear to have survived from the First Interglacial (Ambersham or Abbevillian Interglacial).

It is possible to trace the limits of the area affected by the Main Eastern (Catuvellaunian) ice-sheet by mapping the occurrence of flints in boulder clays. The generalised boundary is shown in Fig. 1. West of Abbots Bromley, and associated with this boulder clay is a wide spread of flint outwash-gravel. This caps several ridges and appears to reach a maximum thickness of 30 ft. The gravel thins rapidly to the west and virtually no flints are found to the west of Bourn Brook.

Boulder clays belonging to the Newer Drift are found to the west of the River Blithe. These more recent boulder clays tend to occur in the valleys as well as on the ridges showing that there has been little subsequent dissection. In addition these boulder clays tend to have a far greater proportion of Foreign erratics (i.e. Lake District and other far travelled igneous rocks) than do the earlier Western drifts. Professor Wills (1948, p. 143) termed this boulder clay the Irish Sea Drift and in the Severn Basin it is clearly of Cornovian age. It has been suggested that it extends over the whole of Needwood Forest (Wills, 1948, p. 112, fig. 29), but this supposition appears to depend on a solitary Lake District erratic at Waterloo Clump, near Burton-on-Trent (Fox-Strangeways, 1905, p. 39), which, by its isolated ridge-top position, would seem to belong to the Older Drift.

The precise boundary of the Newer Drift can be fixed fairly accurately in the area west of Abbots Bromley and again to the north-east of Leek (Jowett & Charlesworth, 1929). Between these two areas lies the drift-free Cheadle coalfield (Barrow, 1903) and the boundary of the Cornovian drift probably lies to the west. Associated with the margin of the Cornovian drift is a fine series of overflow-channels which, north of the Cheadle coalfield, lead to the master-spillway of the Churnet gorge (Jowett & Charlesworth, 1929, pp. 319, 320). To the south of the coalfield less spectacular features lead down to the Blithe Valley, west of Abbots Bromley (personal communication from G. H. Mitchell and shown on unpublished 6 in. maps covering Geol. Survey 1: 63,360, Sheet 140). This eastern margin of the Cornovian Irish Sea Drift is the only Newer Drift occurring in the Middle Trent Basin; the boundary is shown in Fig. 1.

Reference was made in the Introduction to the fluvio-glacial gravels mapped by the Geological Survey. These are shown on the published Geological Survey 1: 63,360 Sheets 141 and 154 (Derby and Lichfield), and recent mapping for the forthcoming Burton-on-Trent Sheet (140) has shown that they also occur north of the Dove, between Uttoxeter and Hilton. Although they have a fairly constant upper limit of 90 ft. above alluvium, they show a wide height-range; for example, of about 35 ft. from 50 to 80 ft. above alluvium west of Sudbury and of 50 ft. from 40 to 90 ft. above alluvium near Borrowash. Because of this the Geological Survey (Fox-Strangeways, 1905) is not prepared to regard them as other than fluvio-glacial deposits. On general morphological grounds, coupled with the probable considerable age of the deposits, they appear, however, to be a true river-terrace, though considerably affected by mass-movement. The deposit was clearly once continuous along the north side of this part of the Dove and has since been dissected by tributary streams. Its character is well shown by the profile of the main Derby–Uttoxeter road (A50) which dips sharply at each stream crossing, while on the interfluves it lies virtually level (see also Fig. 2). The absence of any feature at the back of the deposit is not inconsistent with its formation by aggradation. As it is widespread and well exposed in Hilton parish north of the Dove–Trent confluence, it has been named the Hilton terrace.

It seems probable that the wide height-range of the gravels is partly accounted for by a composite origin for the terrace. A tentative division is proposed into an Upper Hilton terrace with a maximum for the aggradation of about 90 ft. above alluvium, and a Lower Hilton terrace giving wide flats at about 45–60 ft. These may at one time have been separated by a gravel-free bluff, but prolonged mass-movement (probably largely solifluction under peri-glacial conditions) has given a continuous spread of gravel. T. I. Pocock (1929, p. 308) claimed to be able to separate three levels within the Hilton terraces, but the evidence seems very slender.

When the terraces are traced westwards up the Trent, they last occur south of Rugeley, where a patch of terrace-gravel attains a height of 80 ft. above alluvium (042.174). As this implies that there has been 80 ft. of subsequent dissection, it seems to confirm that the Hilton terraces are older than the Cornovian Irish Sea glacier which covered the area to the west. The height of the outwash-gravels of the Cornovian ice-sheet seems to bear this out, for at Rugeley they occur some 60 ft. below the maximum of the Hilton terrace. The presence of flints in these Hilton deposits has already been used to demonstrate that they are later in age than the Catuvellaunian drifts, and this means that the terraces were probably aggraded during the Main (Boyn Hill or Acheulian) Interglacial.

The outwash-deposits from the Cornovian Drift lead down the Trent and occur only a few feet above the principal terrace, the Older Gravels. In some places shown on the Geological Survey 1 : 63,360 Sheet 139 (Stafford), the terrace is actually aggraded against the outwash-gravel. Near Rugeley the terrace is only about 15 ft. above alluvium, but it gradually rises in relative height downstream, until, in what has been taken as the type-area at Beeston, it is 30 ft. above alluvium. From the close association with the outwash-gravels of the Cornovian ice, it seems clear that the Beeston terrace belongs to the succeeding Wolvercote or Micoquian Interglacial. This is broadly confirmed by the archaeological evidence, for the Beeston deposit has in the past yielded artefacts suggested to be of Levallois age (Smith, 1928, p. 91).

In the Trent Valley the Younger Gravels of Swinnerton (1937b) occur beneath the present alluvium and form the most recent member of the chronology. Following the nomenclature adopted for a morphologically similar deposit in the Thames Valley, this has been called the 'Floodplain terrace'. A section near Burton-on-Trent in the Stretton Sewage works (266.255) showed a total thickness of just over 19 ft. of alluvium, peat and gravel (Fox-Strangeways, 1905, p. 64). Comparable thicknesses occur from the new South Staffordshire Waterworks dam on the Blithe, near Abbots Bromley (073.228; 16–17 ft. of gravel), downstream to Sawley just below the Derwent confluence (461.308, 19 ft. of gravel; Fox-Strangeways, 1905, p. 51). Although the gravels 'floor' the present floodplain above Nottingham, below Nottingham the Trent is incised into the Floodplain terrace. This change is accompanied by a steepening in the long profile of the River Trent, and the feature is presumed to be a head of rejuvenation.

It is now possible to summarise the evidence presented by the terraces of the Trent. Although the highest terrace reaches some 90 ft. above the

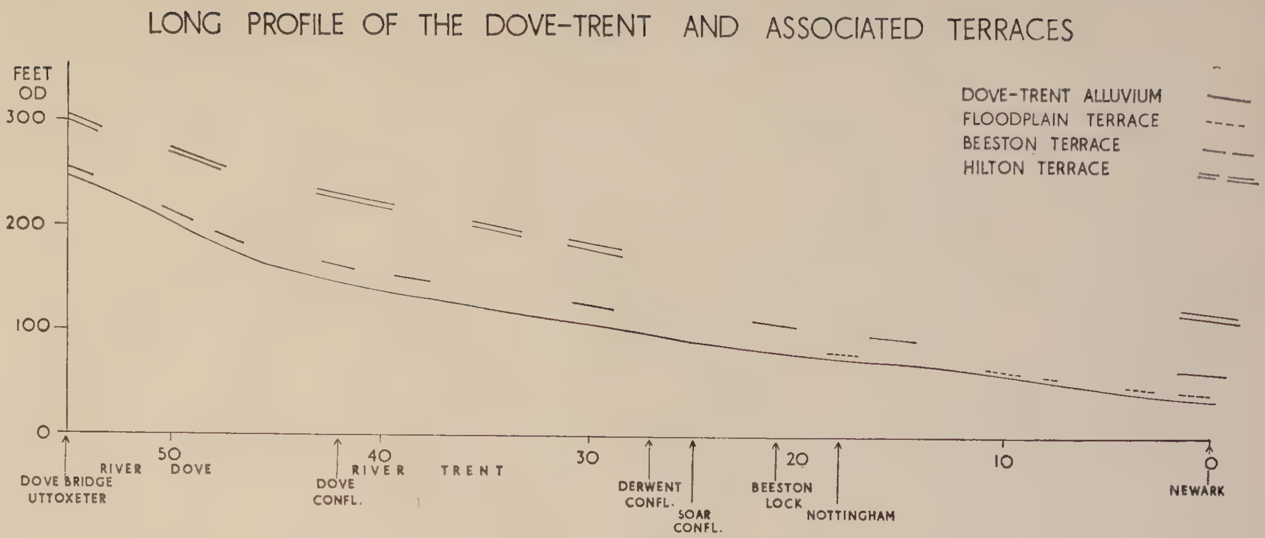

Fig. 2. Long profile of Dove–Trent terraces. Horizontal scale in miles (west of Newark)

present valley-floor, it is possible to arrive at an approximation for the height of the valley-floor at an even earlier stage. As Pennine gravel occurs on the south side of the Trent at Wilford Hill, this must have crossed a shallow Trent vale lying at about the present height of the gravel (Swinnerton, 1948, pp. 77–9). This is 230–40 ft. O.D., or about 150–60 ft. above the present alluvium. The Pennine origin of the gravel and its higher position than the Hilton terrace suggests that this is an approximation for the height of the Trent Valley at the close of the Catuvellaunian Glaciation.

In Table I both the maximum height of each aggradation and the height of the terrace base are given. Similar figures were summarised for the Avon by Miss Tomlinson (1925), and they are given here. The agreement is good, and it is taken to be a confirmation of the correctness of the dating of the various deposits. It also makes it possible to give an estimate of the age of the Floodplain terrace of the Trent. This clearly correlates with the No. 1 terrace of the Avon, and on this showing is probably of Last Interstadial age (Paviland or Aurignacian Interstadial). A. L. Armstrong (1939, p. 101), found what he believed to be Mousterian artefacts in the pits at Attenborough, SW. of Beeston (515.344), so that this dating is not at variance with the archaeological evidence. From this suggested age for the terrace it would seem likely that the rejuvenation which has cut back to Beeston Lock, near Nottingham, dates from the last glacial advance (Cymrian II, or Clwydian of Arkell). It has been pointed out that there is a close similarity between the fauna of the Floodplain terrace of the Trent and No. 2 Avon terrace, which is considered glacial. Although the Floodplain terrace is here described as of Last Interstadial age, this does

Table I. THE LATER STAGES IN THE MIDDLE TRENT AND AVON VALLEYS[1]

TRENT		AVON	
Wilford Hill Gravel (retreat of Catuvellaunian ice)	150–160	No. 5 terrace (outwash Main Eastern ice)	140–150
Upper Hilton terrace	90/?	No. 4	80–90/70
Lower Hilton	55–60/40	No. 3	40–50/30–40
Beeston	35/10	No. 2	30–40/5
Floodplain	0–5/minus 19	No. 1	*ca.*10/minus ?

[1] All heights are feet above alluvium

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SOME MARGINAL DRAINAGE FEATURES OF THE CHALKY BOULDER CLAY ICE-SHEET IN HERTFORDSHIRE

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ABSTRACT.—The paper examines the relations of the Chalky Boulder Clay Drift along the northern margin of the Vale of St. Albans and in the several Chiltern valleys entering it from the north-west. The diversion of the Mimram by a drift-plug in its former valley at Codicote was demonstrated by R. L. Sherlock during the re-survey of the Hertford area. This episode is shown to have been part of a more complicated series of temporary glacial diversions, associated with pro-glacial lakes in the Lea and Harpenden Valleys. The evidence indicates two separate periods of ice-advance, probably associated with the two distinct sheets of Chalky Boulder Clay known in the Vale of St. Albans.

The phenomena described are noteworthy in that they are associated with the 'Older Drift'; most of the classic examples of pro-glacial drainage in Britain are of later date.

1. INTRODUCTION AND PREVIOUS WORK

THE area treated in this paper lies almost wholly within the confines of the Hertford Sheet (239) of the New Series of H.M. Geological Survey. During the original survey, conducted before the Great War of 1914–18, R. L. Sherlock demonstrated that the Mimram Valley was drift-blocked and diverted at Codicote and was thus, in the local sense, pre-glacial (Sherlock, 1919, p. 93, and Note 1). George Barrow superintended the work for a time, and in his wartime Presidential Address he noted the Codicote diversion and added that 'the phenomena occurring along the northern and western edge of the Chalky Boulder Clay deserve minute survey; in particular the butting of the old pre-glacial valley of Harpenden (now a dry valley) against the clay and the deflection of the drainage are worthy of detailed description' (Barrow, 1919, p. 13). Such description is here attempted.

Later papers on the area by Sherlock (1924) and the present writer

(1938) concern its earlier history and particularly the former course of the Thames within it. These discussions do not here concern us except in so far as they permit a sub-division of the mapped drifts into two groups, the main Chalky Boulder Clay drifts and the drifts capping hilltops at a higher level which probably represent a much earlier glaciation (Wooldridge, 1938, p. 645). The recognition of these high level drifts (distinguished as such in Figs. 1 and 5) makes clearer the course of the ice-movement in the later Chalky Boulder Clay phase. The younger drifts essentially occupied the floor of the main Vale of St. Albans and the valleys of some of the Chiltern streams. In broad terms they are the deposits of an ice-lobe advancing down the Vale from the north-east, athwart the openings of the Chiltern valleys. The several diversions here described resulted from this fact. The only other glacial diversion comparable with that at Codicote, and previously noted, is that of the Mimmshall Brook, of which the former valley, now drift-filled, runs from Welham Green to Hatfield *via* the depression at Marshmoor (Wooldridge & Kirkaldy, 1937).

2. RELATIONS OF THE DRIFT IN THE MAIN AREA OF THE VALE

In Fig. 1 the approximate position of the ice-edge bounding the Vale of St. Albans lobe is shown. We may confine attention first to the main area of the Vale, south of the line of hills which ranges from St. Albans to Burnham Green. Along the northern side of the Vale the trend of the ice-boundary is clearly marked. It is notable that, for considerable stretches, the boulder clay here rests directly on Chalk, so that the ice-mass must have ridden close to the bounding heights. This is the relationship south of Burnham Green, around Tewin, where the upper limit of the boulder clay is at about 300 ft. South of Ayot Green it rides higher, to about 350 ft., and beyond the Lea, where the boulder clay ascends the back slope of the high ground at Coleman Green and Woodcockhill (Fig. 2 *c*), it almost reaches the summit of the ridge (*ca.* 375 ft.) for a short distance. The boundary descends to about 260 ft. in crossing the Harpenden Valley south of Sandridge but climbs almost to 350 ft. again on the eastern side of the hill at St. Albans. It then descends rapidly; near Park Street and at the northern end of the Bricket Wood outlier, the boulder clay base is close to 275 ft., falling southwards to about 225 ft. On the south side of the Vale we encounter a complication of which the map itself gives no hint. The mapped boulder clay boundary lies about two miles from the southern side of the Vale, leaving a broad expanse of gravels at the surface around London Colney. This flat, however, is partly, and probably largely, underlain by a lower boulder clay. This is evidenced by a well and a former working for gravel near Colney House; there is no other record

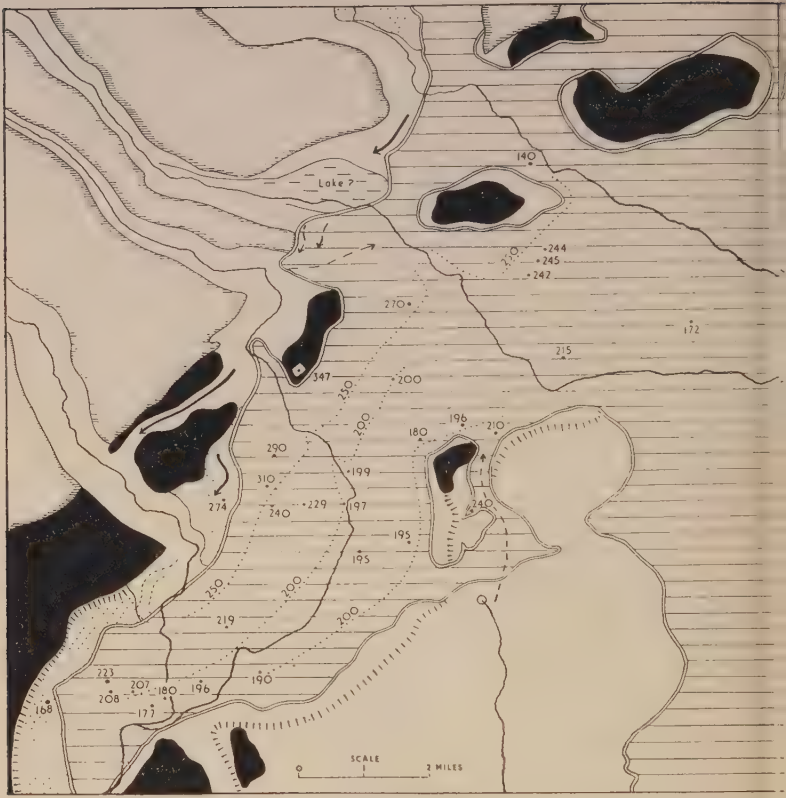

Fig. 1. Generalised map of the drift in the Vale of St. Albans and surrounding areas. (This and succeeding maps should be used in association with the Hertford Sheet H.M. Geol. Surv. N.S. No. 239.)

Explanation: In black—High level glacial or associated deposits.

Edge of Clay-with-flints

Glacial gravels

'Tertiary escarpment'

Sub-drift contours

Area of Chalky Boulder Clay

Spill-way routes

Spill-way or old valley-line now drift-filled in this immediate neighbourhood, but farther NE., where the upper boulder clay comes on, a lower sheet separated from the former by gravel, and resting on gravel over Chalk, is recorded in wells at Colney Heath and Smallford and has been seen in open section near the latter place. In drawing the boundary of the ice-lobe we have, therefore, followed the visible boulder clay edge on the north of the Vale but the gravel-edge on the south. We cannot be sure, indeed, how close the lower boulder clay comes to the mapped gravel-edge, but by drawing the line so we obtain a general indication of the area within the Vale which, at one time or another, was occupied by ice.

South and east of Hatfield, scattered boulder clay outliers in the Tertiary country indicate that the area was widely over-ridden up to a height of 400 ft. The ice-edge, as drawn, leaves the Lea Valley west of Essendon and runs southwards to Potters Bar. It may well have established contact, at maximum spread, with the minor lobe in the Marshmoor Valley, thus encircling the Hatfield Park area, as the spur of Reading Beds, west of Marshmoor, was evidently encircled.

The form of the sub-drift surface beneath the Vale is now known with tolerable certainty in the area west of the main line through Hatfield. Sherlock (1924) noted the sites of some dozen wells which penetrated the drift in this neighbourhood; a larger number is now available (Woodland, 1946). Sites and sub-drift levels are shown in Fig. 1 and approximate contours confirm what Sherlock's earlier records suggest. They show a depression along which the Chalk surface is slightly below 200 ft., lying nearer the southern side of the Vale and broadening eastwards. The pre-glacial drainage of the Vale was evidently towards the east.

3. RELATIONS OF THE DRIFT IN THE CHILTERN VALLEYS

Returning now to the ground north of the broken ridge, which bounds the Vale, we encounter much more complicated relations. Behind this ridge is a series of valleys or cols which afford lateral linkage between the main consequent valleys. These passages are important, for the ice passed through some of the northerly cols, while others furnished a route for temporarily diverted drainage. We must now consider each of the areas in detail.

(a) **The Woolmer Green Valley.** The Great North Road enters the Mimram Valley at Welwyn by a dry valley which, heading at a col south of Knebworth, runs first south-eastwards but swings through more than a right-angle south of Woolmer Green so as to approach Welwyn from the north-east. From the apex of the bend a broad col, floored with boulder clay, leads eastwards past Datchworth Green to the Beane Valley near Watton. Within the Knebworth–Welwyn Valley itself there is evidence that ice, entering by this col, passed both upstream towards Knebworth, where drift lies on the valley-floor, and downstream to Welwyn. In the latter section, outlying masses of boulder clay lie on both valley-sides at about 320 ft., while at a slightly lower level (*ca.* 300 ft.) the dissected remnants of a gravel-terrace make clearly marked features about 50–70 ft. above the present valley floor (cf. p. 229).

These facts may be variously interpreted. They might seem to show that the whole of the valley was pre-glacial and, in due course, drift-filled, but that the lower end had since been largely re-excavated. Alternatively, it may well be that the Knebworth col formerly gave passage to the stream draining the Stevenage Valley and that this turned eastwards to the Beane near Watton *via* the col at Datchworth Green. The marked bend at Woolmer Green may then have been initiated by the advance of the ice from the east and an overspill of drainage to the Mimram. If the lower part of the valley was thus initiated, it was later occupied by the further advance of ice from the east. No decisive choice between these alternatives is at present possible, since we do not know the thickness of the drift in the Datchworth Green col and thus cannot compare its floor-level with that of the valley at Woolmer Green. But if such was not the origin of the bend, we are left without any plausible explanation of it; it would seem then to record an episode of river-capture of unknown cause and of pre-glacial date. We note this occurrence here because of its possible analogy with phenomena farther west.

(b) **The Mimram Valley: Codicote diversion.** Though the diversion by drift of the Mimram at Codicote is only briefly indicated in the Hertford Memoir it was discovered by Sherlock early in the course of the re-survey and described in our PROCEEDINGS in 1913 (see Sherlock, 1919). The line of the old course, now drift-filled, runs from High Heath *via* Codicote to a point near Welwyn Cottage Hospital. The loopway, cut in the Chalk and occupied by the present river, leaves the edge of the drift-plug at Codicote Bottom and trends nearly south for about a mile to the ford at Pulmore Water: here it is fully half a mile west of the plug but it immediately turns eastwards and rejoins the line of the old valley south of the Hospital (Fig. 3).

The well cited by Sherlock at the George and Dragon Inn, Codicote, cannot be far from the centre line of the old valley; it traversed 33 ft. of boulder clay without reaching the base and sufficiently demonstrates that the drift is much more than a superficial capping of the high ground east of the present valley. This has been fully confirmed by the extension, in recent years, of the gravel-pits west of the village; they bite deeply into the heart of the drift-plug, exposing about 50 ft. of gravel with its base on Chalk at about 270 ft. But the relation of the drift-plug to the old valley is apparent quite apart from this evidence, for the valley has been partially re-excavated south of the village. Fig. 2 *a* shows the base of the boulder clay descending from the west to about 250 ft. on the line of the main road, and a boulder clay outlier lies also on the eastern slope of the valley of which the present floor just reaches the underlying Chalk. Farther north, east of the village, this valley is marginal to the plug (Fig. 2 *b*), its eastern slope being wholly in Chalk while the western slope is occupied by boulder clay.

These facts entirely justify Sherlock's conclusion that the Mimram Valley is, in the local sense, pre-glacial, but certain problems remain.

A first question necessarily arises as to the source of the ice which entered the old valley. To this there are two possible answers; the ice may have come down the Mimram Valley from the wind-gap at its head, or over the ridge from the north-east. The writer has been engaged for some years in

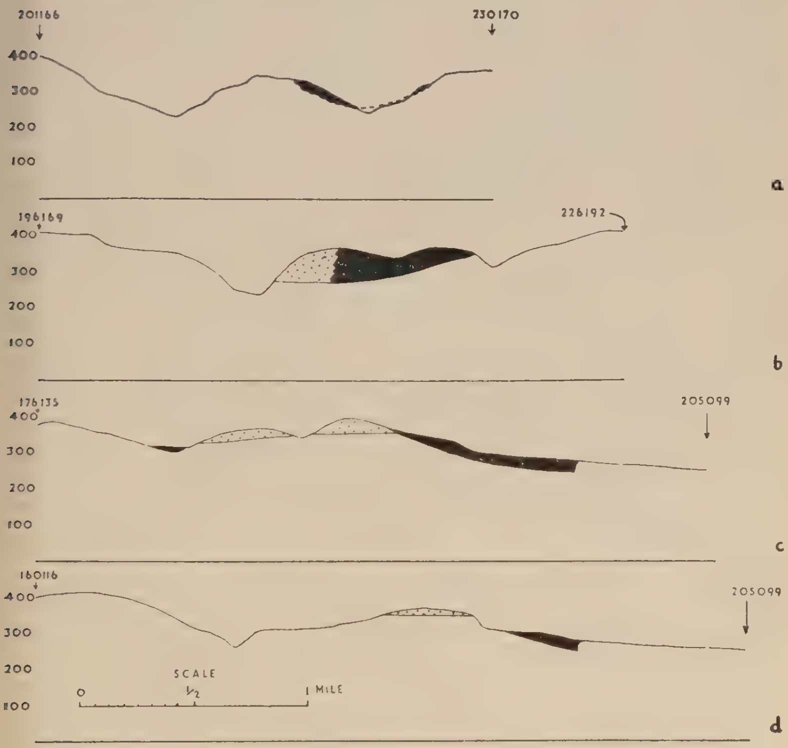

Fig. 2. (a) Section across present and former valleys, south of Codicote. (b) *Ibid.* at Codicote. (c) and (d) Sections across the Coleman Green ridge.
Grid references are given; Boulder clay in black; Gravel, dotted

re-mapping the country north of the margin of the Hertford Sheet; it is rather obscure ground only fully accessible for a short time in autumn when the crops are off. The thick boulder-clay mass of the plug terminates northwards west of Codicote Church (Fig. 3). Northwards from here the Hitchin road runs on a relatively thin sheet of coarse unbedded grave resting on Chalk, which is exposed along the dry valley south of 'The Node'. This gravel-sheet appears to descend westwards towards and into the Mimram Valley. Eastwards the high ground at Knebworth Park and Rabley Heath is largely covered with Clay-with-Flints, but large worn

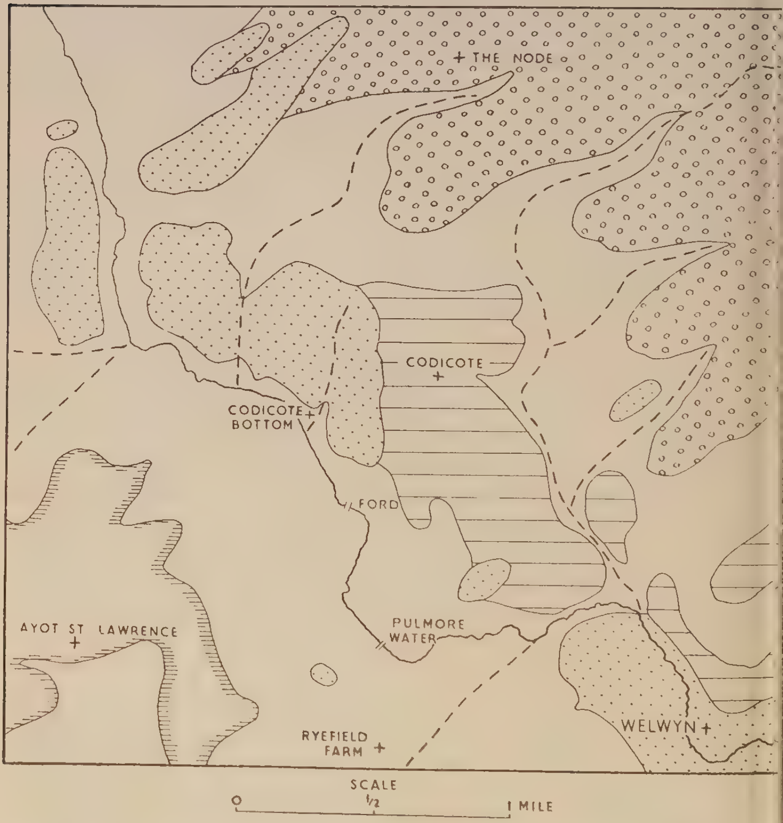

Fig. 3. The geology of the country around Codicote (after H.M. Geol. Surv., extended and modified). Conventions as in Fig. 1 but with glacially modified Clay-with-flints shown thus ◦ ◦ ◦ Lines of dry chalk valleys — — —

flints and Bunter quartzites are conspicuous on the surface in places, as along the southern edge of Knebworth Park. No typical Chalky Boulder Clay has come to light, though the old map (Sheet 46.SE) indicates a small tract of such around Crouch Green west of the main road. Taken as a whole, the evidence might well suggest that at least the upper layers of the ice-sheet surmounted the Knebworth ridge here, and this seems to have been Sherlock's own conclusion. The probable line of advance of the ice from the Beane Valley would have been via a broad col between Datchworth and Shephall, thus gaining access to the Knebworth Valley. While the indications of drift on the high ground west of this do not suggest typical Chalky Boulder Clay, they might well have been produced by some washing and reconstruction of a thin drift-cover. Some confirmation of ice-movement from the east may be offered by the clearly marked N–S. junction of boulder clay and gravel in the Codicote plug. It is quite featureless and is probably vertical or steeply inclined (Fig. 2 *b*), for the high face of the nearest of the gravel-pits, which shows no boulder clay, is within about 200 yds. of the junction. The gravel-mass indeed might well comprise, in part, a kame-like terminal feature in front of the ice.

On the other hand we must take account of the fact that the gravels of the drift-plug at High Heath continue upstream along the Mimram Valley through Hoo Park to Whitwell. This suggests that an outwash-train descended the valley, for Chalky Boulder Clay occurs in Lilley Bottom, the dry head of the valley. There is the further important point that the old map (Sheet 46.SE) shows boulder clay on the valley-side above Whitwell, and though we have no present knowledge of its thickness or exact extent the form of the ground suggests that there may have been another diversion here very similar in its effects to that at Codicote. There is no evidence, however, that the valley was occupied by boulder clay between Whitwell and Codicote and the balance of present evidence favours the emplacement of the Codicote boulder clay by ice from the north-east. Such ice would have imposed a barrier to outwash gravels coming down the valley which may well have become gravel-filled for a considerable distance upstream.

If we now enquire as to the precise mechanism of the diversion, our difficulty is to explain the course of the loopway-channel. If it had been initiated by contemporary ponding and overspill, we should expect it to follow the ice-edge. If it originated later, during or after the melting of the ice, again its most likely line would be at or near the drift-edge. At first sight the channel appears to follow no such line; it is true that from Codicote Bottom it is close to the gravel-margin for some distance, but beyond the first ford downstream it turns south-westwards away from the drift-plug, only turning towards it again below Pulmore Water. But it is to be noted that boulder clay occurs in four outlying masses in the broad saddle to the west between Ayot St. Peter and Ayot St. Lawrence. We have accordingly drawn the ice-front (Fig. 1) almost due southwards from Codicote, crossing the loopway-branch at Pulmore Water so as to include these outliers. When it is so drawn the channel is parallel to the ice-front north of Pulmore Water. This implies that the loopway was not completed until the withdrawal or decay of the ice and there is a strong suggestion that this southern portion utilised and deepened a pre-glacial tributary of the Mimram entering from the west. The head of its valley is still in evidence east of Ryefield Farm and the pre-glacial date of its lower portion is attested by the fact that the southern end of the Codicote boulder-clay plug descends into this valley, west of the Hospital, as it does into the former main valley of the Mimram (Fig. 3).

This reading of the Codicote diversion plainly implies that there was no downstream escape for diverted water at the maximum of glaciation. If the earlier stages of the cutting of the loopway took place along the ice-front, the only possible outlet was across the Ayot saddle into the Lea Valley. There is, in fact, a shallow trench with its floor at about 320 ft. parallel to and just north of Wheathamstead road; this suggests that, for a time at least, drainage passed by this route (Fig. 1).

Here, however, we must call attention to an important well record which has come to hand since Sherlock wrote. Below Welwyn the sides and floor of the Mimram Valley are in glacial gravel, and Chalk does not emerge on the lower valley-side until we reach a point two miles downstream, south of Tewin Water. Here the base of the gravel is at about 200 ft., but more than a mile upstream of this point, at the Pumping Station 550 yds. NNE. of Digswell Church, no fewer than seven wells penetrate to the Chalk. They reveal thicknesses of drift, including thin valley-deposits (8–12 ft.) ranging from 62–73 ft., with the Chalk surface between 137 and 145 ft. The chief constituent of the drift is boulder clay (40–47 ft.) resting on gravels (12–19 ft.). If we take the sub-drift floor of the valley here as at about 140 ft., it descends more than 100 ft. in a mile and a half from the point shown in Fig. 2 *a*. It is possible that we here have evidence of a deep channel excavated beneath the ice comparable with those in the neighbouring Langley–Hitchin Valley and in the Cam and Stour Valleys farther east.

(c) **The Lea and Harpenden Valleys.** We may now consider the interesting relations found in the Lea Valley and its near neighbour, the dry Harpenden Valley. However interpreted they present a complicated story by no means easy to unravel.

(i) *The Lea Valley.* A long tongue of gravels, classed as glacial, passes up the Lea Valley from Lemsford, where it enters the main Vale, to East Hyde, four miles below Luton. Since the Lea rises north of the Chalk escarpment in an area occupied, in part at least, by the Chalky Boulder Clay ice-sheet, we might well expect a train of outwash passing down the valley. It is worthy of note that the gravels near the Eastern Region railway station at Harpenden contain Chalk pebbles together with *Gryphaea* and belemnites (Sherlock & Pocock, 1924, p. 36).

It is essential to recognise, however, that the gravels as mapped comprise at least two distinct sets of deposits. From a point a mile below Wheathamstead, the lower part of the valley is actually cut in gravel which rises in sharp bluffs above a narrow strip of alluvium (Fig. 5). The upper limit of the gravel on the valley-sides is at or below 300 ft. and near Brocket Hall a thickness of 30 ft. is recorded. The available evidence suggests, however, that the Chalk is not far below the present valley-floor. At Waterend House its surface is at 235 ft. beneath only 10 ft. of alluvium, and Chalk is exposed in contact with the alluvium at an elevation of about 220 ft. on the left bank of the river, 600 yds. north-east of Lemsford Church. These figures suggest that the sub-drift floor of the valley grades normally into that of the Vale (Fig. 1) and it is clear that the gravel-filling below Wheathamstead can reasonably be regarded as an integral part of the Chalky Boulder Clay drift.

Near the point where the gravel-filling terminates upstream, a terrace sets in on the north bank, its surface here being 60–70 ft. above the valley-floor. It has been cut into a series of outliers by the deepening of tributary valleys now dry, but can be traced upstream on the north bank to Batsford Mill, and is continued in a narrow strip on the southern bank from near here to a point south of East Hyde. The deposits were formerly worked east of Wheathamstead and in the largest surviving spread revealed a thickness of 26–28 ft. (Sherlock & Pocock, 1924, p. 36). This gives a base-level for the gravels at about 290 ft. The surface of the terrace is singularly level, revealing no consistent or appreciable downstream gradient. The back of the terrace is everywhere at about 325 ft. over a distance of five miles and the 300-ft. contour either crosses the terrace-surface or lies close to its lower edge. Over the same stretch the river falls from 300 ft. to below 250 ft., so that the terrace-surface converges rapidly on the valley-bottom upstream.

In the light of these and other facts it is difficult to regard this feature as a normal river-terrace. There is no comparable feature in neighbouring valleys or any sign of it below Marford. Moreover, there is scant trace of any corresponding feature or stage in the Vale of St. Albans with which t could be correlated (see Note 2). Its projected continuation would pass out over the Vale far above its present floor. It is certainly very significant, however, that this level-topped terrace is found to occupy the Lea Valley from just above the point where the ice-front crossed it (Fig. 1). We are ed thus to the conclusion that the terrace may possibly represent deposits accumulated on a temporary lake-floor. The overflow from the Mimram Valley (p. 216), if it functioned at this date, would have supplemented the filling of any such lake. In seeking confirmation for this suggestion in the character of the deposits, we note first the record of 5–6 ft. of laminated clay above the gravels near Coldharbour, south of East Hyde (Sherlock & Pocock, 1924, p. 36). Adequate exposures are at present few but, in the pits east of Wheathamstead, Sherlock noted that gravel was much mixed with and locally overlain by clay, though the two could not be separated in mapping. Bedded gravels are certainly present in places but there is no reason why such should not have been deposited on the valley-floor before or during the earlier stages of ponding.

Confirmatory evidence of the presence of such a lake is given by the presence of spillways. If we look first at the contour-map (Fig. 4), it at once appears that two cols break the crest of the ridge south of the valley near Marford, at the southern end of the supposed lake and close to the position of the former ice-front. Of these the more westerly, which contains the 'Devil's Dyke' earthwork, has a floor-level just below 325 ft.; its eastern neighbour is shallower with a floor at about 340 ft. Both lead southwards into an east–west furrow north of Coleman Green, in which lies Upper Beechhyde Farm. These facts sufficiently indicate the probability of an overflow of ponded Lea waters; the local distribution of the drift-deposits at once confirms and complicates the picture. The drift-boundaries are shown in Fig. 5; Sherlock confessed to some difficulty in fixing the lines here but repeated examination of the ground has convinced the writer that the boundaries as shown are substantially consistent with al the present evidence. The essential fact is that boulder clay lies in all three of the hollows mentioned. In the eastern col, and the eastern part of the main east–west furrow, its full thickness is unknown and can be judged only from the lowest points of the mapped base. These are at about 330 ft In the western col a well record and former excavations at the Dyke Nurseries give further details, thus recorded by Sherlock (Sherlock & Pocock, 1924, p. 43): 'a well by the roadside at the Nursery . . . records 90 ft. of dirty gravel over the Chalk. Only 150 yds. to the north-west of it bare Chalk occurs at the surface, at a higher level than that of the well while 170 yds. southwards of the well a tank was sunk in 12 ft. of Clay-with-Flints resting on Chalk.' He notes further, what can still be confirmed, that the Devil's Dyke cutting 25–30 ft. deep and just east of the road near the well 'is in reddish loam with small flints and pebbles and gravelly patches' (see Note 3).

It is clear that these records fix, within close limits, the western edge of a deep channel through the ridge. But the ground-level of the well site on the 1:25,000 map is slightly below 325 ft.; this gives the level of the Chalk floor at *ca.* 235 ft., which is lower than the floor of the Lea Valley to the north (*ca*. 250 ft.). There must, evidently, be considerable doubt whether the record gives the true floor-level of the channel. As in all such cases there is the complication of possible sub-surface solution and, again, since the evidence suggests that this channel first functioned as a spillway and was later occupied by ice, we might suppose that it had been over-deepened by iceflow in a restricted passage. It must be noted particularly, however, that the mapping of the boulder clay in no wise confirms such a depth. At the northern end its base descends to 300 ft. on the road at Marford. Southward, beyond Lower Beechhyde Farm, it lies between 300 and 325 ft. All that can safely be concluded is that a drift-filled channel, with a floor at least as low as 300 ft., and perhaps lower, crosses the ridge here. Even in its present form, the col gives a through-way between Lea and Harpenden Valleys below 325 ft.

(ii) *The Harpenden Valley*. Turning now to the Harpenden Valley, it is clear (Fig. 4) that this falls into three well-marked sections. From its head to Nomansland it is a normal dry dip-slope valley. Beyond this point it turns sharply south-westwards to Sandridge and here it is nearly twice as wide (measured between the 350-ft. contours) as it was immediately above Nomansland. At Sandridge the valley turns at right-angles again, so as to pass between the St. Albans ridge and its north-easterly continuation and thus to emerge in the Vale. The line of the valley above this turn is continued in a long dry valley falling eastwards to Sandridge; near its head the spectacular earthwork of Beech Bottom, north of St. Albans, follows the line of its floor. The col at its head affords a through-way, just below 350 ft., leading to the head of another dry valley falling more steeply to the Ver (Fig. 4).

This valley-pattern immediately suggests that the Harpenden Valley was diverted parallel with the ice-edge between Nomansland and Sandridge. This is indeed the fact, but the relations are much more complicated than at first appears, for there can be no doubt that the valley as a whole, including its two sharp turns, is, in some sense, a pre-glacial feature. We have seen that the drift-base descends into the lower section of the valley near Smallford (p. 209), but we have the further rather surprising evidence of an outlier of boulder clay at Sandridge lying between the 300-ft. contour and the valley floor at about 270 ft. (see Note 4 and Fig. 5). Boulder clay also descends almost to 300 ft. westwards from the Devil's Dyke col towards Nomansland. These facts prove that the apparently diverted section of the valley is earlier in date than at least these particular masses of boulder clay. In drawing the ice-edge here we have included the Sandridge boulder clay and that in the hollows south of Marford by inserting two minor 'up-valley' lobes advancing beyond the main ice-mass in the Vale (Fig. 1). It is true that, if the boulder clay at Sandridge is directly linked with that near Nomansland, we are offered a possible ice-front close to, and parallel with, the existing valley-bottom. But the main mass of the boulder clay has every appearance of being banked against the further slope of the high ground east of Sandridge (Fig. 2, c and d) and, though it reaches the crest of the ridge at about 380 ft. near Coleman Green, there is no evidence that it descended its further side into the Sandridge Valley. The essential point, however, is obvious; even if it did so the valley into which it so descended was evidently of pre-glacial date.

These facts completely negative any simple hypothesis of diversion. If, however, we seek for evidence that the Harpenden Valley did suffer diversion, albeit at an earlier date than the emplacement of the existing masses of boulder clay within it, such evidence is immediately forthcoming. We have classed the gravel, which caps the ridge east of Sandridge, as high-level drift (Fig. 1). Mapping fixes its base at about 350 ft. and this is confirmed by a well record at the Wireless Station, but it is in contact with the more extensive gravel-mass west of Coleman Green of which the base is well below 325 ft. immediately to the east of Nomansland (Fig. 5). From this point the base climbs steadily eastwards so as to seem to join that of the higher mass. It is, in fact, occupying a valley or at least resting on its southern slope; immediately to the northwards of the gravel-mass is the east–west furrow floored with boulder clay noted above. The removal of this gravel would evidently offer a wide opening across the ridge immediately opposite the angle of the Harpenden Valley at Nomansland. If this valley ever did cross the ridge it is near here that it must have done so. It is to be remarked that, confining our attention merely to the form of the present land-surface, the east–west furrow itself affords a way through, but this is relatively narrow. It is difficult to avoid the conclusion that the old valley passed, in fact, beneath the gravel-mass, with a floor-level below 325 ft. Supporting this conclusion we have an existing dry valley which continues the supposed line to the Lea Valley south of Waterend. This valley is still largely filled with drift in its upper part. The area is one of the very few in which the writer's mapping differs from that of Dr. Sherlock, who recorded the Chalk as close beneath the surface on the valley-slopes. In fact the old sunken track which follows the valley floor—in part a wet-weather runnel—shows no Chalk at all in its high banks but much gravelly loam with many large stones. The northern slope of the valley appears to the writer to be wholly in drift (Fig. 5) and, though Chalk is near the surface at 325 ft. on the southern slope, most of this slope, too, is heavily drift masked (see Note 5). There can, indeed, be very little doubt that, at a former stage, the Harpenden Valley entered the Lea along this line at about 300 ft., a level in close agreement with that of the base of the presumed lake deposits. We reach thus the inescapable conclusion that the valley was in fact diverted, though necessarily at a distinctly earlier date than the emplacement of the boulder clay at Sandridge.

It will be noticed that this conclusion sets a problem very similar to that presented by the Woolmer Green Valley (p. 212). Here, as there, the whole valley, including its apparently diverted stretches, manifestly pre-dates some one stage of the ice-advance. Here, as there, one might rather implausibly invoke an episode of pre-glacial river-capture but without convincing reason or explanation for such. The difference between the two cases lies in the fact that, with the Harpenden Valley, there is positive evidence of a continuation of the upper valley below the first bend and at least a strong suggestion that it was ice- or drift-plugging which diverted it. We seem, in fact, to have evidence of two distinct periods of ice-advance, one earlier and one later than the diversion. We have noted above (p. 209) the existence of two distinct boulder clays in the Vale, separated, in places at least, by gravels. Parallel with, but of course not necessarily related to, this fact is our requirement for two distinct periods of ice-advance based on physiographic evidence.

(iii) *The suggested sequence of events*. The foregoing brief discussion indicates the lines along which a solution of the complex problem of the relations of the drift around Sandridge and Marford may be sought. We may now sketch, as a working hypothesis, a sequence of events consistent with the observed evidence.

We suggest that an early ice-advance athwart the lines of the Lea and Harpenden Valleys, at or near their former confluence, created a pro-glacial lake in the Lea Valley near Wheathamstead and choked the lower end of the Harpenden Valley so heavily with drift as to lead to its diversion at Nomansland towards the south-west. On this view the valley between here and Sandridge may be regarded as the reversed descendant of a right-bank tributary entering the Harpenden Valley at about the level of the base of the Coleman Green gravel-plug (*ca*. 300–320 ft.). The Beech Bottom Valley and its shallower northern neighbour, which passes Sandridgebury, fall into place as head branches of this valley; it will be noted that to the north a similar right-bank tributary descends to the Harpenden Valley from near Childwick Green (Fig. 4).

The plugging of the Coleman Green outlet would have converted the lower parts of the Harpenden Valley and its Sandridge tributary into a temporary lake which, with rising level, would have sought an outlet. Our hypothesis necessarily assumes that this outlet was found by way of a col notching the ridge south of Sandridge at the head of a pre-glacial valley draining its far slope. It may be remarked that the considerable difference of floor-level between the Sandridge Valley and the main Vale must have favoured the production of such a col. The former, near Sandridge, must have been above 300 ft. in view of its confluence level with the main Harpenden Valley: it may well have been as high as 325 ft. The sub-drift floor of the main Vale, only two miles south of Sandridge, is at about

200 ft. (Fig. 1) and, though it may have suffered some lowering by ice-erosion or water-scour during the first ice-advance, this is not likely to have been large and is certainly not accountable for the whole of the difference in level we have noted. Hence the divide must certainly have migrated towards the Sandridge Valley at the heads of streams on its southern side, and it is at such a point that a col probably existed. The crest of the ridge at its highest cannot greatly have exceeded 350 ft. here, so that a col which notched it to the extent of only 25 ft. or less would evidently have afforded ready escape to waters accumulating in the Sandridge Valley. Our hypothesis assumes that the col was deepened by escaping waters, that the line of the valley from Sandridge southwards was thus initiated, and that such southerly flow was impeded only by the ice-front of the *lower* boulder clay. We cannot know exactly where or how high this stood, but the fortunately placed well record at the 'Horseshoes Nursery', about two miles downstream from Sandridge, gives the top of the lower boulder clay, 23 ft. below the surface, at 227 ft. An ice-sheet rising above this, as base, need not have impeded the initial deepening of a col at, say, 325 ft. Further deepening would have ensued as the earlier ice-mass retired or decayed.

The inferred sequence of events is so far coherent but a difficulty might seem to arise in that the volume of water likely to have been available seems hardly commensurate with the work done, and, on the evidence, rapidly done, in deepening and widening the diverted course. The valley above Sandridge is a basin-like depression a mile wide and more than two miles long (Fig. 4). Most of the work of excavation must be ascribed to this early date. The Harpenden stream with its restricted catchment area, both above and below ground, must always have been a relatively feeble member of the group of Chiltern consequent streams and its probable water-supplies during the onset of glaciation may well have been small. It is here that we may reasonably invoke overflow from the Wheathamstead lake through the col or cols south of Marford. Of the circumstances leading to the initiation of these we can have no precise knowledge, though it is clear that the convergence of the Harpenden stream towards its confluence with the Lea must have left the intervening ridge narrow and probably with an undulating crest. The crest of the ridge south of Wheathamstead today is little more than a quarter of a mile wide and the present form of the ground suggests that the western col is the descendant of a tributary-combe draining south to the Harpenden Valley, while that to the east drained, as it still does, northwards to the Lea. We have, however, no decisive evidence to indicate whether one or both of the cols functioned as spillways and, if both, in which order. But the western col is the deeper of the two and must have carried overflow for a longer time. Water escaping from the Lea Valley by this route may have removed part of the gravel-plug of the old Harpenden Valley. The exceptionally thick and extensive valley-gravels, which floor the present valley above Sandridge, notably at Nomansland, may well mark the later redistribution of gravel thus washed into the Sandridge depression. Such waters must in any case have greatly supplemented those collecting in the Sandridge depression and ultimately escaping from it. To such supplement the magnitude of the resulting widening and deepening of the valley may well owe much.

We come now to the last major episode in the sequence of events which

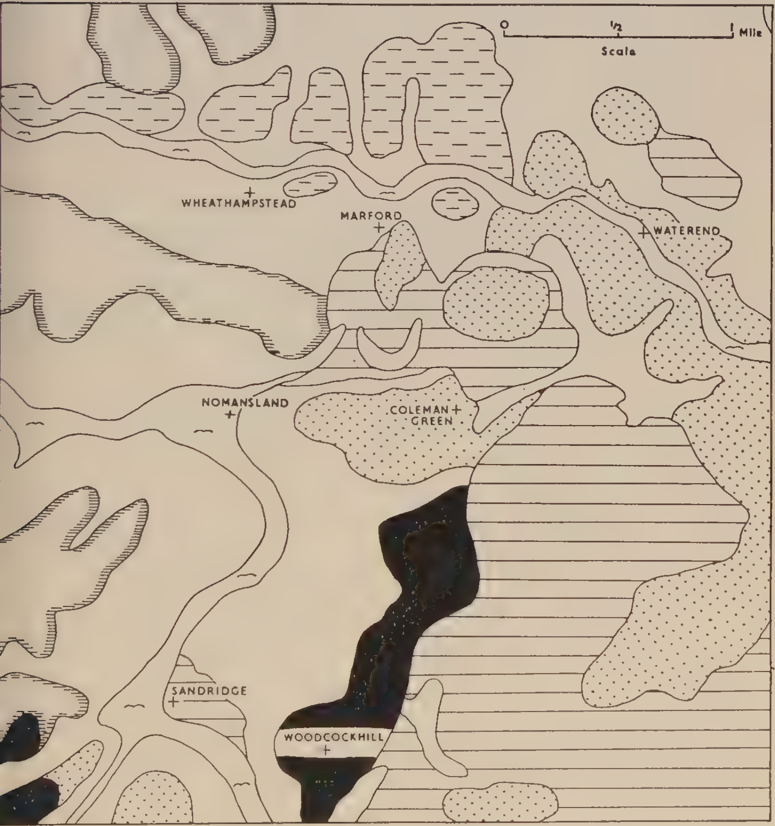

Fig. 5. The geology of the country around Coleman Green (after H.M. Geol. Surv., modified). Conventions as in Fig. 1 but with suggested deposits of pro-glacial lake thus – – – and dry valley gravel thus ⌣

is at all clearly decipherable. After a considerable period renewed ice-advance appears to have closed both the major inlets and the outlet of the Sandridge depression. At this stage, and not before, the ice-front rode well up the south-eastern slope of the bounding ridge and pressed forward up the valley to Sandridge and also into the cols at Marford (Fig. 1). Where the boulder-clay edge today rises to 350 ft. or higher, as near Marshalswick, north-east of St. Albans, or south of Coleman Green, it is clear that the ice itself rose higher still. It is necessary only to assume that it attained 350 ft. across the Marford cols and the valley below Sandridge to find an explanation of the evident spillway at Beech Bottom north of St. Albans. This is beyond question a through-channel between the Sandridge depression and the Ver Valley; its floor, where it breaches the watershed, is almost level, at an elevation just below 350 ft. It can have been cut only when ponded waters stood at about this height in what must have been a considerable pro-glacial lake occupying the Sandridge depression and the valleys tributary to it.

Since P. F. Kendall, half a century ago, first employed overflow-channels as evidence of such former lakes, it has often been a matter for comment and regret that other and confirmatory evidence of their existence and extent so rarely comes to hand. In this instance we have an interesting detail of possibly confirmatory evidence in a faint but distinct terrace-feature such as might mark a temporary lake-shore; it is clearly visible for a distance of some 500 yds. on the northern side of the Sandridge Valley, south of Hillend Farm. It lies almost exactly at 350 ft.

The limited size and depth of the Beech Bottom spillway suggest that it did not operate for long or carry a large volume of water. There is, indeed, a possible supplementary escape-route east of St. Albans. At its highest point, near Marshalswick, the boulder clay does not quite reach the 350-ft. contour which we may take as roughly marking the edge of the pre-glacial hilltop. Of itself this might mean little, for the boulder-clay edge may since have receded somewhat under erosion. If, however, its present position is at or close to the former ice-front, there would have been a narrow gap between it and the hill-slope above (Fig. 4). One would put little weight on this possibility if it were not for the fact that immediately south of the point in question lies the head of a valley, cut in the gravels of the hill-slope, which descends past Fleetville, crosses the main Hatfield road east of the cemetery, and then turns sharply westward, followed by the railway from Hatfield. The whole of the area is now built-up and surface observation is difficult. But it is a significant fact that, throughout the whole of its course, this valley is parallel with the boulder-clay edge. It is clearly probable that it was initiated as an overflow, though it has necessarily been further deepened since, at least at its lower end.

The ultimate outflow from the lake, as the ice-barriers became lowered, must have been via the gap cut south of Sandridge. We have no clear evidence of contemporary conditions in the Lea Valley. The Wheathamstead lake has been implicitly assigned to the earlier glacial phase, but this cannot be claimed as certain. If there was a lake during the second phase in the Lea Valley, we know nothing of its relation to its neighbour in the Harpenden Valley. We may recall, however, that in its present form, the Devil's Dyke col is a channel *in* the boulder-clay filling and, therefore, cut later than this filling. This may have carried waters northward or southward across the ridge here. There is also the east–west furrow north of Coleman Green, on or near the line of the old Harpenden Valley. This is an existing throughway, 330–340 ft. at its highest point, between the Sandridge depression and the Lea Valley.

(d) **The Ver Valley and the Bricket Wood Area.** Finally, we may briefly note the marginal features of the drift-belt between St. Albans and Watford.

As it approaches the Ver Valley, east of Park Street, the base of the boulder clay lies at about 270 ft. It retains this elevation at the northern end of the large Bricket Wood outlier. The ice-front crossed the Ver at, or just north of, Park Street and the floor of the present Ver Valley has inherited a westward deflection close to this line. The isolated hill, just reaching 300 ft. north of Park Street, is a meander core, for the low terrace of the present stream passes north and west of this hill while the narrow strip of more recent alluvium takes the direct route east of it. If, then, we note that, in the recent past, the Ver occupied this loop the extent of the inherited westward deflection becomes still clearer (Fig. 1). The abandoned valley, passing westwards from near Sopwell, crosses Watling Street where this intersects the North Orbital Road. It is here directed towards the narrow gravel-floored strip of low ground west of the boulder-clay edge and followed by the St. Albans–Watford road. Its western limit, approximately along the 300-ft. contour, is the edge of the plateau, covered with gravelly drift, believed to be of an older date (Fig. 1). At the maximum extension of the ice it was along this depression only that the diverted waters of the Ver, supplemented by any overflow from the Sandridge depression, can have escaped southward. So much is clear, but questions necessarily arise concerning the gravels which floor the depression, still well seen at the old pit behind the Black Boy Inn. At first sight these gravels might be regarded as simply part of the gravel-sheet on which the boulder clay rests; near Bricket Wood Station 15 to 18 ft. of such gravels are recorded in wells. This view would imply that the boulder clay had originally extended across them so as to rest against the western slope of the depression. In such case there would have been no spillway for drainage except across the ice itself. This possibility must not be dismissed, for the ice-lobe was here near its termination and probably of small thickness.

There are indications, however, which enforce the claim of the depression west of the boulder-clay outcrop to be regarded as the successor of a drainage-channel. It is, for example, difficult to see why post-glacial erosion should have found and followed this line if there were no inherited hollow to guide it. In fact the depression is marked by post-glacial valley excavation throughout. From its highest point at about 280 ft., close to the junction of the North Orbital and Watford roads, a short dry valley leads eastwards to the Ver at Park Street, while a valley-line is incised below the general floor of the depression southwards past Garston to the Colne, near Aldenham. This valley-line is nowhere in the centre of the depression. Heading on the higher gravel-plateau, near Potters Crouch, it swings into the line of the depression near Lye House and here its excavation has clipped back the boulder-clay edge appreciably. It swings back again to round the high spur capped by boulder clay above the Black Boy Inn, but there turns due southwards close to the boulder-clay edge. Its upper part is dry but it carries a trickle of surface-drainage from near the Building Research Station to the Colne. It is clear that the line thus followed is not necessarily closely related to the course of any earlier marginal drainage. It is presumptive evidence, merely, of a residual hollow west of the boulder-clay edge; the larger depression which it follows is partly filled with gravel and our knowledge of its sub-drift form is very incomplete. At the Black Boy pit the Chalk is exposed beneath the gravel somewhat below 250 ft. South of this point the base of the drift is lower; both boulder-clay and gravel can be mapped resting on Chalk at, or just below, 225 ft. north of the Building Research Station and, though the surface-outcrops nowhere suggest that the drift-base descends much below this, a well at the White House nearby, starting in gravel at 220 ft., penetrates 52 ft. of drift to Chalk, of which the surface is thus at 168 ft. If this marks a deep channel it lies close to, or even beneath, the boulder-clay edge. The thickness of the gravel elsewhere in the depression is at present unknown.

There is one further suggestive item of evidence worthy of note. At its widest, the available channel for marginal drainage can have been little more than 1300 yds. and, near the Black Boy Inn, it can barely have exceeded half this width. One may readily conceive that if marginal drainage was initiated with the first emplacement of the ice it may have been temporarily dammed by further ice-encroachment across the narrow channel. It is important, therefore, to record that, while it was in active work 15–20 years ago, the Black Boy section showed interstratified lenticles of laminated varve-like clay in the gravels.

Taken together these facts support the suggestion that marginal drainage flowed along the depression, excavating it to a considerable depth before it became choked with gravel. We cannot trace the flow of such marginal waters any farther south for we are here close to the end of the ice-tongue, and such drainage must have debouched without restriction on the gravel-plain around Watford, where only the existing streams, so far as they are the direct descendants of outwash-waters, can give any suggestion of routes followed.

4. CONCLUSIONS AND GENERAL DISCUSSION

We may now summarise the features reviewed in this paper and consider them briefly as a whole. They all lie on or near a line which crosses the area from a point about two miles north of Watford, north-eastward to Datchworth Green, near Knebworth, and is everywhere close to the north-western limit of the main sheet of Chalky Boulder Clay drifts.

At Datchworth Green we encounter the first of a series of cols linking the sub-parallel valleys of the Chiltern dip-slope and giving passage to ice or to ice-dammed waters. There is no evidence that this col ever functioned as a spillway but ice passed through it from the Beane Valley to the east and thus entered the Knebworth–Welwyn Valley at its sharp angle near Woolmer Green. It is suggested that the lower part of this valley may have been initiated by means of a direct overflow but that the ice later advanced into it.

The diversion of the Mimram at Codicote is attributed to drift deposited by ice making, farther north, a similar crossing of the ridge west of Knebworth. The upper part of the diverted loopway, which carries the present river, is shown to follow a line close to and parallel with the former ice-front, but its lower part appears to have been guided by a pre-glacial tributary of the Mimram. The ice-front is considered to have run roughly southwards from the Mimram to the Lea Valley across the broad high-level Ayot col within which a marginal channel is indicated.

In the Lea Valley evidence is given of the probable existence of a pro-glacial lake around Wheathamstead of which the deposits form a dissected terrace above the present valley-floor. Two cols south of Marford, both drift-filled, one very deeply, are so placed that they can have carried the overflow of this lake into the neighbouring Harpenden Valley.

This shows complicated features which appear to imply two distinct periods of ice-advance tentatively correlated with the two distinct boulder clays known in the Vale of St. Albans. During the earlier episode the former continuation of the Harpenden Valley to the Lea at Waterend was plugged by drift, and a western diversion, by way of a right-bank tributary, was initiated. The old valley, now drift-filled, remains recognisable and the consequences of this first diversion are plainly written on the map. In the later episode the outlet, cut earlier to the south of Sandridge, was obstructed by ice, and a considerable lake formed with water-level near 350 ft.; this overflowed to the Ver Valley by a spillway at Beech Bottom north of St. Albans, and possibly also south of St. Albans, via Marshalswick and Fleetville. Traces of the strand-line of this lake appear to be preserved locally.

The present Ver Valley inherits the effects of a westward diversion along the ice-edge near Park Street and this marginal-drainage line was probably continued west of the boulder clay at Bricket Wood to the neighbourhood of Garston.

Viewing these several temporary and permanent diversions as a whole, it at once appears that the crucial ground is that which we have discussed at length between the Lea and the Ver. If it were not for the evidence here afforded, one would quite naturally infer that all the westward deflections of drainage dated from the same phase, that of the maximum expansion of a single ice-sheet. This evidence suggests two distinct episodes of ice-advance. Two questions thus arise. The first takes us into the disputed field of general glacial chronology and cannot be pursued at length. It should be made clear, however, that, in the writer's judgment, the two glacial phases mark, not distinct glacial periods, but fluctuations within a single period. It is true that the Chalky Boulder Clay in the Thames Basin has been confidently ascribed by different authors to both the Mindel and the Riss glaciations and there is, therefore, some ground for surmising that it may include representatives of both. But these two glaciations are separated by the 'Great Interglacial'. We certainly cannot, without further evidence, find room for this between the upper and lower boulder clays in the Vale of St. Albans. They are lithologically almost identical and, as Dr. Woldstedt recently pointed out to the writer, the upper surface of the lower sheet, as seen near Colney Heath, is not weathered. Moreover, the physiographic work, which we have ascribed to the interval between them, though considerable, is hardly commensurate with the supposed length of the 'Great Interglacial'.

This brings us naturally to the second point at issue. The existence of two boulder clays no doubt strengthens the argument we have presented, but the evidence is notably incomplete. At the inferred earlier phase we require an ice-front sufficiently near to Coleman Green to obstruct directly, or indirectly, with drift, the lower end of the Harpenden Valley, but at the same time we require this same ice-front to hold sufficiently back from the Sandridge gap to allow its unimpeded cutting. Now, although we know of the lower boulder clay south of Sandridge and can reasonably infer a front here, we have no present knowledge whatever of the position of this same front east of Coleman Green, where the surface lies, to all appearance, wholly on the upper boulder clay. A single well section might abolish this difficulty, or again temporary sections may reveal lower boulder clay in the vicinity. We mention these facts to indicate the need for continued observation of the area.

A further important problem immediately appears if we ask to which of the two periods of ice-advance the diversions east of the Lea are to be ascribed; whenever, in the earlier part of this paper, we have spoken of 'the ice-front' the later pages pose the implicit question 'which ice-front?' and we must attempt an answer to it.

It will be recalled that our suggested interpretation of the Woolmer Green Valley itself implies two periods of ice-advance, the melt-waters of the first initiating the lower part of the valley, later itself occupied by ice; but these might well be incidents of a single progressive advance and do not of themselves help us to distinguish two boulder clays. We have, however, the highly important fact that what must certainly be the lower boulder clay occurs in force in the Mimram Valley at Digswell (p. 216) and must extend upstream to or towards Welwyn. If the earlier ice-front lay near here we might hope to find evidence of pro-glacial ponding in the Mimram Valley and its tributaries above this point. Possible evidence of such is offered by the dissected terrace noted in the dry valley between Welwyn and Woolmer Green (p. 212); it is closely similar in situation and elevation to the Wheathamstead terrace in the Lea and might similarly be interpreted as representing a former lake-floor. Ponding on this scale, however, implies a considerable thickness for the earlier ice-sheet. The surface of the lower boulder clay at Digswell is at about 200 ft. If we regard this as near the original surface, we require an ice-thickness of at least 100 ft. to hold up a water-surface at 300 ft. in the valley to the north. In fact it is an excessive estimate since the upper surface of the boulder clay must have been lowered by the later erosion; valley-deposits rest directly upon it. The figure, however, is probably of the right order of magnitude.

Following this line of reasoning we should naturally conclude that the ice-advance, which emplaced the boulder clay above 300 ft. east of Welwyn, the Codicote drift-plug, and the boulder clay at *ca.* 350 ft. in the Ayot col, marks the later phase. There is, indeed, a more general argument in favour of this view. In the earlier phase the main tract of the Vale was wholly open to ice-movement and there was less occasion for what has been termed 'transfluence', the lateral diversion of the ice-stream through high pre-glacial cols (Linton, 1951). In the later phase the low ground of the main Vale was already occupied, perhaps in part by surviving ice, but certainly by drift. Such upstream congestion as might have led to the over-riding of the Knebworth ridge and the Ayot col may well have been thus assisted.

We return, thus, to the critical area in the Lea Valley above Lemsford, westwards to Coleman Green, and here little of use can be added to the discussion. If our reading of the physiographic facts is correct, we require an ice-front of the earlier phase both to cause pro-glacial damming and to initiate a diversion of the Harpenden Valley. We cannot at present separate two boulder clays here and a doubt concerning the date of the Wheathamstead lake thus inevitably remains. It seems probable, however, that the lower boulder clay may well be found to lie, as in the Mimram Valley, within the general mass of drift which fills the lower part of the valley between Waterend and Lemsford.

ACKNOWLEDGMENTS

We have noted that the greater part of the ground here treated was mapped by Dr. R. L. Sherlock nearly forty years ago. Apart from the early note on the Codicote diversion his later work did not concern itself with the features here described nor are they discussed in the Hertford Memoir. Nevertheless, much of the evidence used derives from his mapping and the writer originally hoped that this paper might be written jointly. The separation imposed upon us by the war years and Sherlock's death in 1948 made this impossible. For this reason it is the more both a duty and a pleasure to testify to his very careful and objective mapping in the area; it well stands the test, in general, of the closest examination and of the new evidence yielded by many temporary sections since opened. To our understanding of the area, George Barrow in a few brief years also contributed much. At the first meeting of the Association attended by the writer as a young student, he delivered the Address from which we have quoted. It opened a new chapter in London geology and stimulated much of the work of later years. In particular, there can be little doubt that Barrow perceived the complexities and foreshadowed the interpretation of the drainage-development of the area. To both these friends of former days the debt of the writer is very great.

NOTES

Note 1 (p. 208). Throughout this paper the term 'pre-glacial' is used in all local contexts in the sense of 'earlier than the local drift'. In days when we have come to recognise the length and composite nature of the Pleistocene Glaciation this may seem at first a dubious expedient. But, in fact, unless it is used in such a sense, it can hardly be used at all as is evident from the disputed position of the Pliocene-Pleistocene boundary. Some would dispute, for instance, whether the Red Crag could properly be styled pre-glacial in the stratigraphical sense. In our present area we are similarly precluded from all use of the term if we choose to give weight to evidence that suggests that the higher level drifts embody the record of a glaciation earlier than that of the Chalky Boulder Clay. Moreover the evidence here presented suggests that the Chalky Boulder Clay episode is itself composite. One thus becomes continually involved in clumsy periphrasis and qualification. There seems thus good warrant for retaining the term 'pre-glacial', especially when dealing with land-forms, in the sense of 'earlier than the immediately local drift'.

Note 2 (p. 217). The base of the high-level gravels at Roe Green, near Hatfield, is at about 280–290 ft., but to link the terrace with these is a far cry across an otherwise vacant area. The only really comparable feature in the area is the terrace in the dry valley north-east of Welwyn (p. 212). A further possible reading of the facts would regard the surface of the Wheathamstead terrace at 300+ ft. as continued by the flat upper surface of the gravel-fill farther downstream, as near Cromer Hyde at about 275–280 ft. But this merely defers the difficulty for there is still nothing in the main Vale area even possibly correlative with such a stage.

We may further note that the most northerly outlier of the Wheathamstead terrace near East Hyde lies distinctly above 325 ft. and it may well represent the end of a gravel-train descending to the lake from the Luton gap.

Note 3 (p. 218). The 'dirty gravel' of the well record was mapped by Sherlock as boulder clay; this seems justifiable and consistent with the surface evidence. The materials seen in the Devil's Dyke cutting could certainly be mapped as nothing else though it reveals little or no chalky content.

Note 4 (p. 219). The Hertford Memoir makes no mention of the evidence on which this outlier was mapped but its existence is not in doubt. It was exposed over twenty years ago in a working now overgrown 500 yds. south-east by east of Sandridge Church. Most of the ground has since been built over but surface indications can still be seen in the lane leading up to Woodcockhill.

Note 5 (p. 220). This area is of great importance and temporary sections may well yield vital evidence. A large solution-hollow, from which Chalk Dell Farm takes its name, occurs by the roadside of the northern slope of the valley at about 330–340 ft. This shows Chalk beneath a considerable cover of stony loam and the ground should certainly not be mapped as bare Chalk. Chalk is not turned up by the plough even on the lower parts of this slope. It is certainly at or near the surface over parts of the southern slope where the boulder clay comes on with a good feature above. The writer believes that the old drift-filled channel lies in part at least beneath the northern slope, later excavation having followed the line excentric to the original drift plug.

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REPORT OF SUMMER FIELD MEETING IN SOUTH SHROPSHIRE, 1952

By Professor W. F. Whittard; with contributions by Drs. H. W. Ball, F. G. H. Blyth, D. L. Dineley, J. H. James, G. H. Mitchell, R. W. Pocock and C. J. Stubblefield.

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THE summer meeting in southern Shropshire was held over the fortnight, 16–30 August, and fifty-one members and friends attended all, or some only, of the excursions. Craven Arms was chosen as the centre from which the daily excursions were conducted.

Sunday, 17 August

The section exposed in the Onny River, $1\frac{2}{3}$ miles south of Craven Arms, shows shales and nodular limestones which underlie the typical Aymestry Limestone. The nodules yielded fragments of *Monograptus* cf. *tumescens* Wood; the Aymestry Limestone in this region cannot be younger than the base of the *leintwardinensis* Zone. The quarries on the hillside above Lower Park are excavated in massive-bedded Aymestry Limestone; they are situated to the east of the line of the fullest development of the *Conchidium* shell-banks, and consequently provided only a few fragmentary specimens of that pentamerid.

The ascending Ludlovian succession above the Aymestry Limestone was demonstrated in quarries alongside the road to Onibury in *Dayia* Shales, *Camarotoechia* Beds and *Chonetes* Beds. In the latter quarry, the *Chonetes* Beds above are separated from the *Camarotoechia* Beds below by a 'Concretion-Band' about two feet thick;[1] discussion of the origin of this bed showed general support for its formation by slumping. After visiting the quarry in the Downton Castle Sandstone at Onibury and collecting from the Temeside Shales near the bend in the Norton Lane, lunch was taken in the quarries at Weo Edge, famous for their abundance of *Conchidium knighti* (J. Sowerby). A comparison was made between the moderately well-bedded Aymestry Limestone, examined earlier in the day, and the shell-banks at Weo Edge; chert was also seen at the latter locality.

Returning to Craven Arms, the coach put the party down at the turn for Coston Cottage, near Aston-on-Clun. Near The Hollies, the view showed eastwards the Silurian escarpments and northwards the Pre-Cambrian mass of Hopesay and Wartle Knoll; the line of the Church Stretton fault-zone was traced. The Hoar Edge Grit in the quarry at Coston yielded a rich haul of *Flexicalymene caractaci* (Salter), *Marro-*

[1] Elles, G. L. & I. L. Slater. 1906. The highest Silurian rocks of the Ludlow District. *Quart. Journ. Geol. Soc. Lond.*, 62, 215.

lithus, *Horderleyella*, *Heterorthis patera* (Salter), *Harknessella vespertilio* (J. de C. Sowerby) and geniculate strophomenids.

Just north of The Hollies a lane was followed westwards to a quarry near Shelveswell Cottage, east-north-east of Clunbury. A *Chonetes striatellus* fauna was obtained from rocks which are lithologically distinct from beds of comparable age at Onibury. The dip was noted as being towards the east, that is, towards the Ordovician of Coston. Between The Hollies and Shelveswell Quarry, the Church Stretton Fault had been crossed, and here the easterly dip is regional towards this fault. The pronounced change in facies of the *Chonetes* Beds was explained as occurring at the line of the fault. (W.F.W.)

Monday, 18 August

The party travelled by coach from Craven Arms via Church Stretton, Atcham and Overley Hill to Buckatree Glen, between the Ercall and Lawrence Hill. The basal Cambrian Quartzite was seen at the western entrance to the glen. On this side of the Wrekin range, it is in faulted contact with the Uriconian rocks which are well exposed in quarries in the glen and yield examples of flow-banded and pyromeridal rhyolites. At the eastern end of the glen, the quartzite rests unconformably upon the Uriconian and nearly its whole thickness, dipping steeply to the south-east, can be examined in the large Ercall quarry, now being worked at three levels. The members noted the large amount of debris of Uriconian rocks contained in the lower beds of the quartzite and also the thin partings of dark grey clay between the beds. Certain conical structures, described as spring-pits, had been found at one horizon in the quartzite and these were believed to be due to freshwater springs rising through the sand of the Cambrian foreshore.[1] At the eastern side of the quarry, the quartzite passes through passage beds into the overlying glauconitic Comley Sandstone. Here, in the top-level quarry, glauconitic sandstones occur some 30 ft. above the quartzite and yielded to Mr. R. H. Hoare a brachiopod, identified by Dr. Stubblefield as *Micromitra* (*Paterina*) *phillipsi* Holl. Earlier in the year, in the mid-level quarry in beds transitional between the quartzite and the Comley Sandstone, Dr. Stubblefield had found hyolithids, including one resembling *Hyolithus strettonensis* (Cobbold), *Micromitra* (*Paterina*) sp., and conchostracan crustacea in a light-grey, fine-grained, sandy limestone concretion lying among shales and glauconitic sandstones, some 2 ft. 6 in. below a conglomerate band.

Proceeding to the Forest Glen the party ascended the Wrekin, crossing the Cambrian–Uriconian contact at two points on the way to Wrekin Cottage, and thence traversing the North-east Pyroclastic Group on to the pyromeridal and flow-banded Summit Rhyolite. On returning to Forest

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[1] Pocock, R. W. 1937. *Quart. Journ. Geol. Soc. Lond.*, 93, cxxiv–v.

Glen, the Uriconian pyroclastic rocks were examined in Lawrence Hill quarry alongside the Pavilion. Here special attention was drawn to a bed of tuff with pebbles and large boulders of rhyolite, tuff and vein-quartz which has been called a bomb-rock, but which appears to be more in the nature of an agglomerate. The pyroclastic rocks are penetrated by two dolerite dykes.

Continuing half a mile south-east to Maddock's Hill quarry, an intrusion of camptonite in the Shineton Shales was examined and the contact metamorphism noted.[1] Specimens of *Dictyonema* were collected; some months previously, Mr. J. T. Wattison had the unusual find of a pygidium of *Niobe* (*Niobella*) *homfrayi* Salter. From Maddock's Hill the escarpment of the Carboniferous Limestone, with contemporaneous Little Wenlock Basalt, was ascended on the road past Willowmoor, and a brief halt was made on the hill to examine the basalt exposed in the road bank. The rock was seen to be highly vesicular and it was suggested that here the lava flow was thinning westwards from its probable origin, somewhere in the Doseley area to the east. At Little Wenlock it is no longer possible to see either the bole at the top of the basalt or the overlying Carboniferous Limestone.

The large quarry in the Little Wenlock Basalt at Doseley shows a face of columnar basalt up to 100 ft. in height. The basalt rests upon sandstone, apparently the Lower Carboniferous Lydebrook Sandstone, and in places large masses of sandstone and clay rise up from the floor into the basalt. These are thought to have been caught up by the flow of the lava. The top of the basalt is much decomposed and is overlain by Coal Measures, the lowest beds of which appear to be composed largely of weathered basaltic material; at Stoney Hill, to the south-west in Lydebrook Dingle, the basement bed of the Coal Measures is a conglomerate of basalt fragments and rests on Lydebrook Sandstone.

After examining the interesting features of Doseley quarry, the party went on to Ironbridge, in the Severn Valley, where the ancient iron bridge was inspected and a brief account was given of the origin of the gorge by overflow of the waters of Lake Lapworth in the later stages of the Glacial Period. (R.W.P.)

Tuesday, 19 August

The party travelled via Cressage to Charlton Hill where the Uriconian and Cambrian rocks form a southward-pitching anticline, much broken by faults and separated by the Charlton Hill fault from the Rushton syncline, in which the Cambrian rocks rest on the Rushton Schists. There is evidence in Charlton Hill that the principal movement along the fault has been horizontal, and, assuming this to be the case, we may dissect the geological map and, by aligning the various sections of the Cambrian Quartzite, produce a plan of the ground as it might have been before faulting occurred.[1] The quartzite was examined at the roadside at the southern end of Charlton Hill, where it dips off the Uriconian rocks at about 45°S. A prominent dyke of felsite in the Uriconian was seen, and the outcrop of the Charlton Hill conglomerate found; this is believed to be the same band as occurs in the small inlier of Brom Hill, to the south, and again in Charlton Lane. These three bands fall into line in the plan mentioned above. The section in Charlton Lane exposes the Cambrian Quartzite and overlying glauconitic Comley Sandstone resting at an angle of 55° on the Uriconian rocks, in which the conglomerate occurs.

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[1] Chapman, R. W. 1950. Contact metamorphism at Maddocks Hill near Wellington, Shropshire. *Geol. Mag.*, London, 87, 86–8.

From Charlton Lane the route was northwards along the Rushton road for a quarter of a mile and thence eastwards into the fields crossing the Charlton Hill fault on to the Rushton syncline. The next section was at the upper end of the Charlton Hill branch of Dryton Brook where the Comley Sandstone and the *Callavia* Beds were found, and some of the higher Lower Cambrian limestones yielded *Helenia cancellata* Cobbold, *Hyolithellus?* and *Obolella* spp. Continuing eastwards, shales and calcareous grits belonging to the upper part of the Middle Cambrian were seen in the Rushton branch of Dryton Brook; the section was in poor condition but cranidia of *Agraulos robustus* Cobbold were obtained from the shales.

The Rushton Schists were seen in the roadside at Rushton; there are other exposures of this rock-type in the tract of ground extending westwards to the Charlton Hill fault, and northwards to Bell Brook, where a dyke of granophyre, 27 ft. wide, cuts greenish schist. A halt was made at Eaton Constantine where there is a great concentration of glacial boulders; these boulders, and similar concentrations near Uppington and along the north-western flank of the Wrockwardine ridge, at or near the 300-ft. level, may have been dropped by icefloes on Lake Lapworth brought by currents converging on the overflow at Ironbridge Gorge. (R.W.P.)

As an introduction to the Shineton Shales in their type area, the important implications of Callaway's (1877) disentanglement of the Shineton Shales (Tremadoc) from the Harnage Shales (Caradoc) was stressed, and a summary of the subsequent stratigraphical and palaeontological work on the Shineton Shales was given. The director also commented on the lack of natural exposures of the Shineton Shales, except in stream-valleys, and on the relationship of the rejuvenation of these streams to the formation of the Ironbridge Gorge.

The party proceeded on foot north-eastwards along the deeply cut and wooded Marrys Dingle into Cherme's Dingle across the outcrop of the

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[1] Cobbold, E. S. & R. W. Pocock. 1933. The Cambrian area of Rushton (Shropshire). *Phil. Trans. Roy. Soc. Lond.*, (B), 223, No. 501, 319.

Shineton Shale *Clonograptus tenellus* Zone. From the basal beds of this zone, bitheca-bearing *Clonograptus* and '*Bryograptus*' were collected associated with *Protospongia*. From the succeeding Transition Beds (to the *Dictyonema flabelliforme* Zone), trilobites, including some 'complete' *Euloma monile praemonile* Lake and fragments of *Macropyge chermi* Stubblefield, were obtained as well as *Dictyonema flabelliforme* (Eichwald), *Hyolithus magnificus* Bulman, *Acrotreta* and *Lingulella*. The party then returned to the coach at Leighton and proceeded via Cressage to Cound Lodge Inn, situated on Uriconian in the Church Stretton fault-zone. After tea, a harvest of trilobites from the *Shumardia pusilla* Zone was gathered along with *Macrocystella* at the lower of the two well-known cliff-exposures at Shineton, but the zone-fossil was not found. (C.J.S.)

Wednesday, 20 August

Comley was reached via Church Stretton and the outcrop of the Shineton Shales on the western slopes of Hoar Edge was indicated; the absence of the Upper Dolgelly black shales with stinkstones containing *Ctenopyge flagellifera* (Angelin), though known to occur two miles to the north-east, was explained as possibly due to their being cut out by the most eastern branch of the Church Stretton fault-zone in Shoot Rough Wood. The first exposures visited were those where the stream from Shoot Rough Wood joins Comley Brook (Cobbold's Exposure 60); here, in the Dolgelly *Parabolina spinulosa* Zone ('Ca' of Cobbold's notation), *Orusia lenticularis* (Wahlenburg) was collected from calcareous concretions in grey shales along with lingulellids. A downward traverse of the Cambrian succession was started to the uppermost Middle Cambrian glauconitic grits in Shoot Rough Road (Cobbold's Exposure 21) where *Billingsella* Beds (Bc) are seen in a north-westerly-trending anticline. Here tribute was paid to Cobbold's patient trenching and collecting campaign in development of the research begun by Callaway, Lapworth and Groom; Cobbold's (1927) ideas of the geological structure of the area were demonstrated using an enlarged copy of his published map. The party walked to Comley quarry which, though derelict, still yielded from the scree an inch-diameter fragment of *Callavia* cephalon in *Callavia* 'Limestone' (Ac_2), also fossiliferous pieces of *Strenuella* Limestone (Ac_4). Passing over the outcrop of Middle Cambrian, the *Callavia* 'Limestone' was again seen in the road-surface on the rise to Dairy Hill here surrounded by Middle Cambrian. Lunch was taken near Cobbold's Exposure 47 of green *Callavia* Sandstone (Ac_1) on the banks of the brook, 400 yds. south of Comley Quarry. A new excavation in the Middle Cambrian Comley Breccia (Bb), 660 yds south of the quarry, was examined on Hill House Ridge (Plate 11). Buried

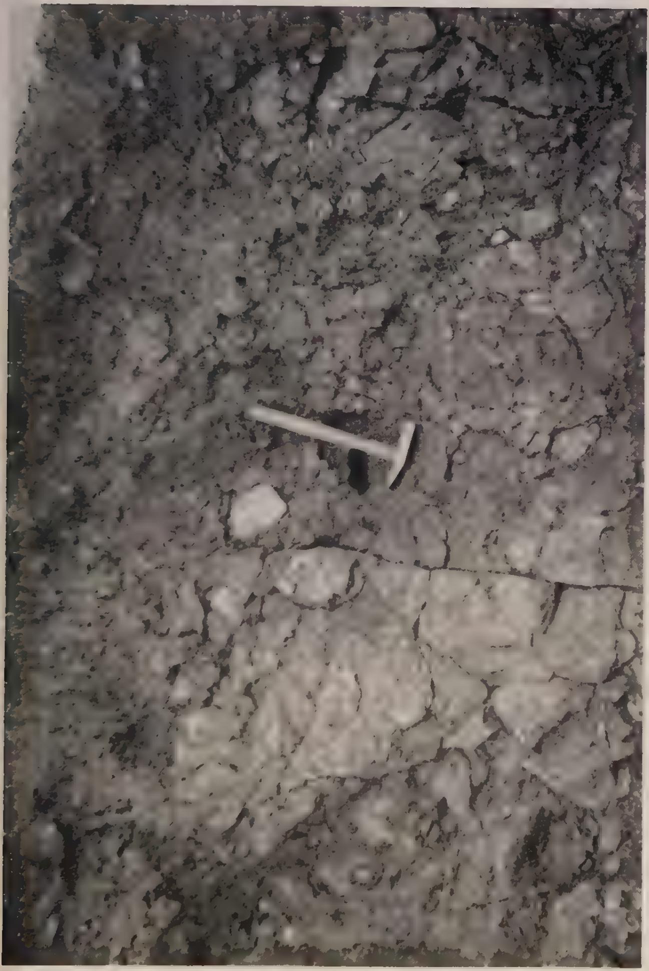

Photo: W. F. Whittard

Comley Breccia (Middle Cambrian), Hill House Ridge, Comley.
(For explanation see page 250)

in a glauconitic gritty matrix, weathered blocks of '*Eodiscus*' *bellimarginatus* Limestone (Ac_3), up to 10 in. in diameter, proved to be very fossiliferous; in order of abundance they yielded *Callavia* spp. (many fragments), *Strenuella pustulata* (Cobbold), *Dipharus attleborensis* (Shaler and Foerste), *Serrodiscus* [*Eodiscus*] *bellimarginatus* (Shaler and Foerste) and *Obolus parvulus* Cobbold. These fossils were preserved in a white egg-shell-like texture. From fragments of soft green glauconitic sandstone (Ac_I), limonitic moulds of *Callavia* were collected. The gritty matrix itself yielded limonitic moulds of Middle Cambrian fossils such as *Bailiella cobboldi* Resser, *Helcionella oblonga* Cobbold and whiter fragments of *Paradoxides* skeletons, as well as occasional Lower Cambrian fossils—in some cases as limonitic moulds, in others as white skeletons. As Cobbold stated in his early description of other finds of this breccia-bed in this area, it is difficult to decide sometimes whether a particular fossil belongs to the matrix or is remanié. It would seem that disintegration of the matrix of some of the Lower Cambrian fossils has left them isolated in a Middle Cambrian matrix.

The traverse continued across the Ordovician syncline in The Cwms, where basal Caradoc calcareous grits were noticed to be fossiliferous, to reach Cobbold's Exposure 53; here the basal Comley Sandstone *Obolella groomi* Beds (Ab_I) failed, on this occasion, to yield fossils. (C.J.S.)

On the way down to The Cwms, the general distribution of the outcrops of rhyolite, andesite and halleflinta of Uriconian age on the eastern slopes of Caer Caradoc was pointed out, and the more rounded topography of the ground occupied by dolerite intrusions was noticed. Several members ascended the lower slopes to examine an outcrop formed of the highly vesicular rhyolite, which forms the most prominent crags of the hill, including the eastern battlements of the camp itself. (G.H.M.)

The Helmeth Grits in the Hazler Old Road, Church Stretton, are now much obscured by the metalled surface of the road. Their stratigraphical position between the Uriconian and the Watling Shales (Stretton Series) of the Longmyndian was remarked upon, and, on the evidence of the contained angular fragments of Uriconian age, it was claimed that the Uriconian was the oldest of the exposed sequence. Reference was also made to the occurrence within the Uriconian of rocks difficult to differentiate from the Helmeth Grits, the main distinction being that the tuffs of the so-called Helmeth Grits are interbedded in green and purple Longmyndian shales, and those of the Uriconian are included within volcanic rocks.

Proceeding round the western flank of Hazler Hill, a quarry alongside the lane to Ragdon showed two neptunean dykes contained within Uriconian volcanic rocks; the dykes yielded a Harnagian fauna. The party walked to the Sandford Seat to join the coach. (W.F.W.)

Thursday, 21 August

The traverse of the Longmynd commenced with Brockhurst Shales exposed at the War Memorial at All Stretton; here occur cone-in-cone nodules of limestone. Proceeding up the Batch Valley, the marker horizons in the stratigraphical and tectonic succession were seen, beginning with the oligoclase-quartz, cherty tuff of the Buckstone Rock. Owing to the lack of readily accessible exposures within the Burway Group, the Cardingmill 'Grit' was next visited and the current-bedding used to show the normal sequence at this horizon. The change from the predominant greenish grey coloration of the Burway Group to the abrupt incoming of the purple tints of the Synalds Group was pointed out. The marker horizon of the andesitic tuffs, known as the Batch Volcanic Group, was visited, small east–west tear-faults were traced, and fracture-cleavage was used to determine the stratigraphical sequence. Continuing up Jonathan's Hollow another marker-horizon, the Haddon Hill 'Grit' at the base of the Lightspout Group, was seen at Jonathan's Rock.

The party now proceeded across country to Deadmans Batch, whence Dr. Pocock indicated the landmarks on the Midland Plain formed by the Trias. On the northern slopes of Deadmans Batch, the Huckster Conglomerate, which normally lies above the Lightspout Group, was found to be about 450 ft. from the Batch Volcanic Group; in the absence of faulting, this indicated an overlap of more than 2000 ft. of strata. Yet at High Park cross-roads, 900 ft. to the south-west, the Huckster Conglomerate occupies its normal position. At High Park Hollow a quarry exposes coarse grits similar to those of the Huckster horizon but at a higher position in the Portway Group.

The route now lay via Wildmoor Pool to Catsbatch for localities, first, in the Darnford Conglomerate and, secondly, in the better exposed Stanbatch Conglomerate of the Bayston Group. Following the strike of the latter conglomerate across the Longmynd to Bilbatch, the remainder of the Bayston Group was examined in roadside exposures on the way to The Bridges, particular notice being taken of the incoming of thin shales as the Bridges Group is approached. At Drives Coppice, 1000 ft. to the east of The Bridges, an exposure shows fine cross-laminations which indicate that the eastern portion of the Bridges Group is here in normal succession. The typical red siltstones and shales were seen at Wier quarry, alongside the road to Bishop's Castle. (J.H.J.)

Friday, 22 August

The coach was taken to the southern entrance of Linley Drive, and thence sent round to the western entrance. By kind permission of Mr. Jasper More of Linley Hall the party walked along Linley Drive to Chittol

Wood where the conglomerate, or boulder-bed, of the Western Longmyndian and the underlying green shaly tuffs were inspected. The party climbed to the hilltop to see the small patch of Uriconian rocks resting upon the graded-bedded shaly tuffs which indicate an inverted relationship. (J.H.J.)

The lane along the south-west margin of Chittol Wood was followed, first, across Tremadocian shales, which hereabouts have proved unfossiliferous and contain small doleritic intrusions, and, secondly, on to the Stiperstones Quartzite, which commences the Arenig succession and was examined in a small adit, excavated above the road for barytes. Continuing westwards in the direction of dip of the Ordovician rocks, the small breadth of outcrop of the Mytton Flags and Hope Shales was shown to be due to an important tear-fault which runs along the south-east side of Cefn Gwynlle slightly oblique to the strike of the rocks. At Nind,[1] the Stapeley Volcanic Group consists of bedded tuffs alternating with shales, and here a typical fauna—including *Agnostus* cf. *maccoyi* Salter, *Ampyx mammillatus austini* (Portlock), *Ampyx* cf. *nudus* (Murchison), *Placoparina sedgwicki* (McCoy), *Cyclopyge binodosa* (Salter), *Dionide rotundata* Whittard, *Dionide turnbulli* Whittington, *Platycalymene tasgarensis* Shirley and trinucleids—has been collected. Linley Drive was followed to the lodge at the western entrance; the coach took the road southwards to the lane leading to Llan, where the party now started on the western traverse by foot to Alport, which is situated on the road from Church Stoke to Chirbury. At Llan, the Stapeley Volcanic Group is again exposed but the dip is in the opposite direction to that seen at Nind due to the crossing of the Ritton Castle syncline. A route was now selected past the old cock-fighting pit at Pinfold to St. Ethelreda's Church, and thence west-north-westwards towards Brithdir. (W.F.W.). *En route*, an exposure of the Cwm-mawr augite-picrite was examined; this rock is the ultrabasic member of a series of related intrusions which are mainly doleritic in character. The form of the picrite-intrusion is probably a sheet, but contacts are not exposed. The picrite was the material used for the fabrication of recently described stone axes.[2] (F.G.H.B.)

Hope Shales crop out in the track immediately west of Brithdir and have yielded *Agnostus morei* Salter, *Ampyx mammillatus austini*, *Placoparina sedgwicki*, *Barrandia* cf. *cordai* McCoy, *Homalopteon portlocki* (Salter)-*Dionide turnbulli*, *Pharostoma pulchrum* (Barrande), *'Illaenopsis' acuti, caudata* Hicks, *Dindymene* sp. and *Trinucleus murchisoni* Salter. The dip of these beds, and of the overlying Stapeley Volcanic Group, is again westwards, due to the crossing in our traverse from Nind to Brithdir of the southerly continuation of the Shelve anticline; the Cwm-mawr picrite may occupy the crest of this fold. Continuing westwards the intrusive andesite of Roundton Hill was viewed from the ridge formed by the westerly-inclined Stapeley Volcanic Group. The road to Old Church Stoke was followed over Weston Flags; between that locality and Brynkin Green an important strike-fault cuts out the Betton Beds and most of the Rorrington Beds, and both these subdivisions fail to reappear farther south in the Shelve Inlier. At the head of Brynkin Dingle, the Spy Wood Grit is faulted against Rorrington Beds to the south and Aldress Shales to the north; the Aldress Shales are well exposed along the dingle and beyond its confluence with the Spy Wood Dingle. A short distance east of where the Spy Wood stream joins the River Camlad, the Hagley Volcanic Group appears in good exposures, which are interesting because water-bedded tuffs here yield graptolites. A southerly route was now followed to Rock Cottage and a lane section in the Hagley Shales was examined on the way to Alport, where the coach was joined. The misfit drainage of the River Camlad at Church Stoke was discussed. (W.F.W.)

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[1] This is the modern misspelling of Neint.

[2] Shotton, F. W., L. F. Chitty & W. A. Seaby. 1952. A new centre for stone axe dispersal on the Welsh Border. *Proc. Prehist. Soc.*, London, 17, 159–67.

The intrusive pyroxene-andesite of Simon's Castle, at the southern end of Todleth Hill, was inspected in the quarry on the southern side of the road from Church Stoke to Bishop's Castle. At the Squilver road-metal quarries, the main characters of the coarse-grained dolerite, the calcite-epidote-prehnite veins which penetrate the rock, and its faulted eastern boundary against vertical Hope Shales, were demonstrated. The base of this sill is probably not far below the level of the main quarry, and Watts has recorded having seen the shales below the igneous rock in an adit which is now blocked by the weighing machine. The concordant upper contact of the Squilver dolerite, inclined west below metasomatised mudstones, was seen at the entrance to the smaller quarry. Here the igneous rock becomes more albitic at its margin, and has given rise to a narrow belt of adinolisation in the adjacent sediments; a zone of spotted rock follows outside the adinoles. (F.G.H.B.)

Saturday, 23 August

The first locality to be visited in the traverse across part of the northern portion of the Shelve Inlier was at the tip-heaps just to the east of the school at White Grit. The bluish-black shales of the Mytton Flags yielded *Niobella selwyni* (Salter), *Monobolina plumbea* (Salter) and *Redonia anglica* Salter. At Shelve Church the Mytton Flags are exceptional in providing a rich variety of dendroids, extensiform graptolites, *Glyptograptus dentatus* (Brongniart), *Oxydiscus*(?) *perturbatus* (J. de C. Sowerby), fragments of *Cyclopyge*, an undescribed odontopleurid, and other fossils. Returning to White Grit, specimens were collected from another tip-heap from the Mytton Flags situated on Shelve Hill north-east of where the road leaves the open hill and runs between fences down to the cross-roads; a fauna similar to that of the first tip-heap was obtained but it included, in addition, an undescribed raphiophorid. (W.F.W.)

Corndon was ascended from Cliffdale Mine via the western slopes, where old quarries in spotted shales reveal the contact-metamorphism associated with the intrusion of the dolerite phacolith. The latter is situated on the crest of a dome with a nearly north–south axis. The course of the north-easterly fault, which crosses the hill along a marked depression, was indicated and, after proceeding to the top of the eastern crags, the jointing in the dolerite, which gives a clue to the form of the intrusion, was discussed. Sheet-jointing dips outwards on three sides of the hill, and may be taken as parallel to the original roof of the dolerite. This feature, taken in conjunction with the occurrence of much fine-grained dolerite in the eastern screes and with other evidence, indicates that the boundary of the dolerite outcrop is the trace of the upper surface of the phacolith and not the base as was formerly thought. Near the summit of Corndon, a variety of the rock holding micrographic areas of quartz and felspar was inspected; this probably represents nearly the highest part of the intrusion, where a small amount of residual liquid, rich in silica, crystallised to give the micrographic patches. (F.G.H.B.) The view from the top of Corndon included the Malverns and Clee Hills in the south-east, the pronounced ridge of the back of the Longmynd, which may be partly controlled by faulting, and the several quartzite pinnacles formed along the Stiperstones. North-westwards and westwards the succession of the Berwyns, Arenig, Aran, Cader Idris and Plynlimmon was clearly outlined, and farther round towards the south the Black Mountains were recognised.

On returning to Cliffdale Mine, the track was followed by the stone-circle of Mitchell's Fold, across the upper part of the Stapeley Volcanic Group and the Stapeley Shales into the deeply excavated valley south of Rorrington Hill Covert where tuffs, interbedded in Weston Shales, contain innumerable *Didymograptus bifidus* (Hall) and shells. The stratigraphical sequence was now descended by crossing the rough country leading to Holywell Burn, and small tuning-fork graptolites, possibly allied to *D. bifidus*, were recovered from the Stapeley Shales. The Holywell Burn was followed downstream, the crags formed by Weston Flags were noted and *Ogyginus corndensis* (Murchison) was collected just north-west of where the stream leaves the bracken-covered hills and flows through meadows; representative faunas from the Betton Beds and the Meadowtown Beds were found south and south-south-west of The Mount. The Ordovician succession, studied the previous day, was connected by visiting exposures in the graptolitic Rorrington Beds, where the Grey Grass Dingle is crossed by the road to Marton, and in the Spy Wood Grit found inside a field gate on the south of the road 100 yds. to the west, where a starfish bed, no more than 1½ in. thick, has provided a few dozen specimens of *Protaster salteri* Salter. (W.F.W.)

Sunday, 24 August

The day was devoted to visiting several of Bancroft's localities in the Ordovician succession of the region of the Onny River. The classical section alongside the river, showing the unconformity between the Purple Shales of the Upper Valentian and the youngest Ordovician rocks, was easily accessible; the Onny Shales have yielded a rich trilobite fauna of which the cryptolithid *Onnia superba* (Bancroft) is common, but some of the rarer species, such as *Lonchodomas pennatus* (La Touche), *Remopleurides burmeisteri* Bancroft, *Triarthrus* sp., were also found. The northern bank was followed westwards to 80 yds. beyond the position where the Batch Gutter joins the Onny; hereabouts, good exposures of the Acton Scott Beds are seen in the river-bed and in the southern bank; the fauna is varied but *Lichas*, *Chasmops* and the brachiopod *Reuschella semiglobata* Bancroft can usually be collected. Continuing along the southern bank, collecting places in the top two subdivisions of the Marshbrookian, that is, the *Kjerulfina polycyma* Beds above and the *Wattsella unguis* Beds below, are available, but the *Wattsella wattsi* Beds are not exposed. The defunct Bishop's Castle Railway was crossed and the type-locality for *Kjaerina typa* Bancroft was examined in a small quarry alongside the lane at the north-east corner of Burrells Coppice; the *Kjaerina geniculata* Beds at the top of the Upper Longvillian are exposed here. On regaining the railway track, no exposures of the *Broeggerolithus transiens* Beds are available but the *Heterorthis alternata* Limestone can readily be picked out, and this marks the base of the Upper Longmyndian.

The underlying Lower Longvillian and Soudleyan, of Bancroft's classification, comprise grey, green and purple sandstones which are exceedingly difficult to subdivide in the field; they were collectively known previously as the Horderley Sandstone. Several small quarries in these sandstones showed the lithological range of the rocks and provided many examples of *Sowerbyella*, but the rarer brachiopods, like *Kjaerina hedstroemi* Bancroft and *Dinorthis* (*Plaesiomys*) *multiplicata* Bancroft, were not found. After crossing the lane running northwards over Longville Common, the stream section in the Harnage Shales 200 yds. east-north-east of Smeathen yielded *Broeggerolithus broeggeri* (Bancroft).

The path to the north-north-east of Smeathen was taken to the quarry on the south side of the Onny which exposes about 70 ft. of the Hoar Edge Grit; about three feet of Harnage Shales occur at the top of the quarry at its eastern end, and to the west the junction of the Hoar Edge

Grit with weathered Western Longmyndian arkoses is exposed. It was decided that movement had complicated the unconformable relationship between the Ordovician and Pre-Cambrian.[1] The return was made to Smeathen, thence across Longville Common and by road past Wood House to the cart-track in the replanted area immediately south of Smeathen Wood. Here the Hoar Edge Grit and the Harnage Shales crop out, and the latter yielded *Phacopidina harnagensis* Bancroft, *Salterolithus smeathenensis* Bancroft, *Flexicalymene acantha* Bancroft, *Diacalymene praecox* Bancroft, brachiopods and Polyzoa.

A traverse of the Caradoc rocks in ascending stratigraphical sequence was commenced by walking through Longville Plantation to the road to Cheney Longville, but the first stop was at a roadside exposure in the *Heterorthis alternata* Limestone, from which large slabs, with the zone-fossil decalcified, were obtained; the locality is 100 ft. south-east of where the 600-ft. contour cuts the Cheney Longville road. Continuing along the road, opportunity was given to collect the faunas from those horizons which had not been examined during the morning's traverse; these were the *Broeggerolithus transiens* Beds (mid-Lower Longvillian), 110 yds. from the *Heterorthis alternata* Limestone, the type-locality for *Kjaerina geniculata* Bancroft, 100 yds. up the lane from the northern corner of the Earthwork, and the *Wattsella wattsi* Beds of the base of the Marshbrookian visible in the bank immediately opposite the earthwork. (W.F.W.)

Monday, 25 August

The journey to Buildwas was made by way of Church Stretton, Leebotwood, Acton Burnell and Cressage. A representative fauna was collected from the Buildwas Beds in the bed of the River Severn, but this popular section has deteriorated of recent years; the Purple Shales of the Upper Valentian were not seen on this occasion. (R.W.P.) Returning to the coach and approaching Ironbridge, attention was directed to the hummocky topography of the lower slopes of the Wenlock Shale outcrop resulting from numerous landslips, and the difficulties of maintaining a good road were evident. Passing through Ironbridge, the road to Jackfield was taken and the party walked across the recent large landslip at that locality. This landslip, one of many which are constantly occurring in the Ironbridge Gorge, caused considerable damage in the winter of 1951–2, and is still moving. It is comparatively shallow-seated, the clays and mudstones of the Upper Coal Measures moving downhill in a manner more like a mudflow than a true landslip. The instability of the slopes is clearly due to the steepness of the sides of the glacial overflow-gorge, and many examples of older, similar slips were seen. The striking damage caused by the Jackfield slip includes the wrecking of houses, the breaking of two roads, and a large flow of material into the River Severn. A gang is constantly employed maintaining the railway track by slewing the metals and reballasting the track. (G.H.M.)

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[1] The quarry has been obscured for more than thirty years. A mapping class from the University of Bristol has recently excavated the western end of the quarry and a diagrammatic sketch of the rocks which were exposed is given in Fig. 1. A thin band of fault-gouge is developed at the junction between the Ordovician and Pre-Cambrian; the Hoar Edge Grit is disturbed (although some of the irregularity is due to hill-creep) and its outcrop, as traced from the south, suddenly thins from 150 to 70 ft. measured in the quarry. A fault, which runs slightly oblique to, and more easterly than, the strike of the Hoar Edge Grit, is believed to define in the quarry the Ordovician–Pre-Cambrian contact.

The party rejoined the coach, travelled to Much Wenlock, followed the Craven Arms road, and halted at Stretton Westwood to collect from one of the many quarries in the Wenlock Limestone. At Presthope quarry, north-east of the Plough Inn, coral-reef rock in the Wenlock Limestone forms domal masses of unstratified limestone, or ballstone, and is rich in corals and stromatoporoids. The coral-reef rock passes into rubbly limestone which shows a crude stratification. The road from Presthope to Bourton crosses over higher Silurian rocks. The Ludlow Bone Bed was seen at Brockton, but it is not so richly fossiliferous as were the sections at one time available at Ludlow and at Norton Farm.

The afternoon was devoted to a traverse through the Ludlovian rocks of the Millichope area. The first of four quarries to be visited in the Aymestry Group is 250 yds. north-west of Hungerford Farm, and here Dr. Shirley has reported the association of *Monograptus leintwardinensis* Lapworth with a shelly fauna. At the southern end of Slang Coppice, *Atrypa reticularis* (Linnaeus) and *Sphaerirhynchia wilsoni* (J. Sowerby) are common, on the south of the road to Upper Millichope *Dayia navicula* (J. de C. Sowerby) and *Chonetes striatellus* (Dalman) were found and opposite the lodge to Millichope Park, from a quarry near the base of the Aymestry Group, *Strophonella euglypha* (Dalman) was the most plentiful brachiopod. Lower Ludlow Shales are exposed in a dingle on the east of the road, about midway between Blackwood Farm and Upper Millichope; they yielded a mixed fauna of monograptids of the *nilssoni* Zone, and *Dalmanites* cf. *vulgaris* (Salter), nautiloids and brachiopods.

Continuing to Roman Bank, past Rushbury, where herring-bone pattern (Saxon) shows in the stonework at the base of the church, the unconformity between the Harnagian and Uriconian was examined in the farmyard at Hope Bowdler. The return to Craven Arms was made along the Marshbrook–Horderley road to see Scaldbank Gutter and the gorge cut by the overspill from the lake, which was dammed by the Irish Sea ice against the head of the Church Stretton valley near Minton. (W.F.W.)

Tuesday, 26 August

The Long Mountain was approached by road via Cothercott Hill, Minsterley, and Westbury, and the southerly crossing commenced at Isfryn, one third mile east of Middletown cross-roads. Comparisons were

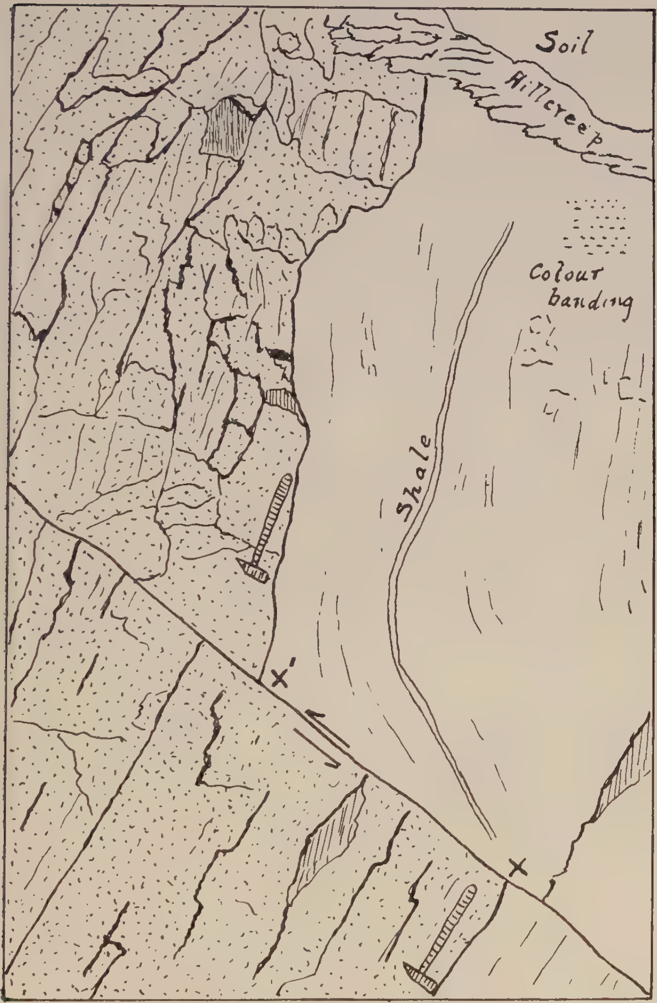

Fig. 1. Drawing made from a photograph of the quarry on the south side of the River Onny, 100 yards south of Rock Cottage, Horderley. The contact is shown between the Hoar Edge Grit, on the left (east), and the Western Longmyndian arkoses, on the right; the strata are highly inclined to the east. The contact, marked by the hammers, is displaced 2 ft. 6 in. from x to x′ by a small thrust. The Longmyndian is incoherent and leached to a light brownish-grey tint, but sometimes the original maroon colour is preserved in the cores of harder bands; in some places, horizontal colour-banding is developed but it is obviously of secondary origin. A thin band of greenish-grey shale shows pronounced drag effects

made between the shelly faunas and calcareous lithologies of the Wenlockian and Ludlovian Series, already seen in the Wenlock Edge area, and the graptolite-rich shales and flags of the Long Mountain. From Isfryn, the path to the footbridge over the stream led to exposures in the *linnarssoni* Zone, and cyrtograptids and monograptids were found. The *rigidus* Zone crops out in the same stream a short distance before the railway is reached, and the best exposures in the *lundgreni* Zone are again in the stream but directly south of Middletown Station. The footpath on the east of the stream was followed to a position west-south-west of Glyn for graptolitic beds of the *vulgaris* Zone. The path to Glyn Common was ascended, and the lane past Old Parr's Cottage first took the party to an exposure in weathered *nilssoni* Beds and then to the road, where the coach was waiting. At Upper Winnington, rocks included in the *leintwardinensis* Zone were the last to be examined on the northern side of the Long Mountain syncline. The coach went over the Upper Ludlovian and Downtonian to the cross-roads at Rowley, whence it was sent round to Brockton. A walk of just under a mile along the road leading westwards brought the party to a quarry in the topmost flags and shales of the *leintwardinensis* Zone; in addition to the zone-fossil, good specimens of *Slava interrupta* (J. de C. Sowerby) were recovered; attention was also directed to the change in regional dip which was now northerly. Immediately south of the quarry, in the stream in Tantree Bank, typical slabs of *M. leintwardinensis* were common. A fauna from the *tumescens* Zone received special attention 400 yds. upstream from Walton Mill because the zone is cut out on the north flank of the syncline by the unconformable *leintwardinensis* Zone. The descending stratigraphical sequence was crossed past Walton Mill into Beachfield Dingle where there are many excellent outcrops in a strike-section of the *nilssoni* Beds. At Hampton Beech the road leads to Newmills where, a short distance to the east, it crosses Brockton Brook. Here the basal beds of the *lundgreni* Zone crop out and show irregular limestone bands; just before the footpath reaches the road at Brockton, the nodular limestone at the top of this zone provided no fossils. From Brockton, where no older Wenlockian rocks are visible owing to the cover of alluvium, the road to Chirbury was taken and at Walcot Farm graptolites from the *riccartonensis* Zone were obtained from the only locality known to be in this zone in the Long Mountain district. The marginal overflow channel of Marrington Dingle was pointed out on the return journey. (W.F.W.)

Wednesday, 27 August

The coach followed along Long Lane, near Craven Arms, and stopped at the Long Lane quarries for specimens of *Wattsella horderleyensis* Bancroft which occur in the Lower Longvillian exposed in the north-western quarry.

Proceeding westwards beyond Wartle Knoll, the party crossed the most westerly of the Church Stretton Faults (F1) and followed the lane past Grist House to a quarry 250 yds. farther on, where *Dayia navicula* occurs in abundance in dark greenish-grey flaggy shales which clearly belong to a different facies from the *Dayia* Beds seen on the first excursion on 17 August. The fault F1 thus introduces on the west a facies of Upper Ludlovian rocks different from that known on the east, and later in the day this was found to hold good for the Wenlockian. Returning to Round Oak, the path was taken to the top of Wartle Knoll over volcanic agglomerates and felsites of Uriconian age. Wartle Knoll is probably the finest viewpoint for the geologist in Shropshire and from here the observer can also look along the line of the Church Stretton displacement. The coach returned the party to Craven Arms; the Horderley road was followed and, at Brokenstones, a mixed fauna of monograptids and shells were found in the Wenlock Shales of the 'sand pit'. F1 passes immediately to the south-east of this small quarry and brings Wenlockian against Pre-Cambrian. The latter crops out in the stream by the culvert-bridge; a short distance downstream, near an intrusion of spilitic basalt, an excavation made earlier in the year revealed conglomerates and arkoses of the Western Longmyndian resting upon green shales and cherty beds which forcibly recall the Eastern Longmyndian of about the horizon of the Buckstone Rock. More extensive excavation is needed here because the rock-relationships are slightly obscured by fault-gouge, but there is every reason to anticipate that in the stream-section, and at a locality near the Round House, an unconformity between the Western and Eastern Longmyndian can be exposed. At Cwm Head Farm, Wenlockian rocks with interbedded flaggy limestones resemble, but are not identical with, the Wenlock Limestone. The rocks are situated within the Church Stretton fault-belt; they differ in facies from the Wenlockian previously examined in the 'sand pit', again testifying to the importance of F1 in controlling facies.

The south-eastern flank of the Longmynd was reached by walking along the lane to Hamperley and so to Prior's Holt, where the track and footpath leading south-westwards to Hillend Farm afforded an opportunity to demonstrate the Upper Valentian shoreline with its attendant pebble-beaches and sea-stacks. The Upper Valentian unconformity was traced east of Hillend Farm, and the details of the mapping of a beach 300 yds. south-west of this farm were shown.[1] After collecting the fauna of the *Pentamerus* Beds at a roadside quarry west of Hillend Bridge the party returned to Craven Arms by coach. (W.F.W.)

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[1] Whittard, W. F. 1932. The stratigraphy of the Valentian rocks of Shropshire. The Longmynd–Shelve and Breidden outcrops. *Quart Journ. Geol. Soc. Lond.*, 88, 892–3, pls. 49 and 52.

Thursday, 28 August

A non-stop journey from Craven Arms to Breidden quarry at Criggion was made by way of Welshpool and Buttington. After collecting samples of the dolerite, noting the jointing and seeing the shales lying underneath the intrusion, the party went by coach to the Admiral Rodney Inn where a traverse on foot across the northern part of the Breidden Inlier began. The lane was followed past Newtown, and, immediately west of where the southerly branch crosses a stream, a quarry shows a black grit of which the stratigraphical position was shown later in the day to be at the *Nemagraptus gracilis* Zone. The route led southwards and upwards through thick undergrowth until it was possible for some members of the party to cross to the stream which flows northwards at the western end of Pritchard's Hill. Traced downstream, two waterfalls are formed by dolerites intruded into shales; one foot below the lower surface of the second dolerite some ill-preserved graptolites were collected. On rejoining the rest of the party, several fields were crossed to reach the road from Bulthy to Crew Green. A track along the northern edge of New Plantation shows good sections in the Middle Shales, but they proved unfossiliferous. Continuing uphill, the crest of the ridge formed by the Upper Volcanic Group was followed to Bausley Hill, where transverse faulting affecting the ridge was demonstrated and a shelly fauna was recovered from the bedded tuffs. The traverse of the highest Ordovician rocks of the region now lay in a south-easterly direction and, at the head of the easterly branch of the stream passing Bryn-poeth, some highly fossiliferous calcareous flags yielded many cryptolithids and brachiopods. About midway along Braggington Coppice the stream cuts through the soft Braggington Shales which have been stained to a reddish tint by the overlying Coal Measures (Ruabon Marls). The Ordovician age of the shales was proved by the graptolites and cryptolithids. The unconformity between the Coal Measures and Caradoc rocks was located; fossil plants were obtained farther downstream from light grey shales of the Upper Coal Measures and, 200 yds. north-west of Lower Braggington Farm, a *Spirorbis* limestone yielded typical specimens. The Braggington Lane brought the party to the main road at Coedway, and, walking past old tip-heaps and shafts, a field path, a few yards west of The Hollies, led down to the bank of the River Severn where black grit, similar to that seen at Newtown, is associated with shales containing *Nemagraptus* and other basal Caradoc graptolites.

After tea at Welshpool, the Shrewsbury road was chosen; the agglomerate at Trewern, the intrusive andesite of Moel-y-golfa, the position of the Upper Valentian unconformity, and the south-westerly continuation of the Upper Volcanic Group from Bausley into Middletown Hill were noted from the coach. The Alberbury Breccia (Upper Coal Measures) i well displayed in roadside quarries near Cardeston and, after motoring through Shrewsbury to see the new High Cross, which was erected a few months ago to mark the fourth centenary of the founding of Shrewsbury School, the main road southwards to Craven Arms provided excellent views of the Stretton Hills and of the Wrekin. (W.F.W.)

Friday, 29 August

Taking the road across the Silurian to Corvedale, three distinct levels are prominent, viz. the lowland of the Downton Series, the Ditton platform and the higher land of the Clee Series and Carboniferous. The first halt made was at the laneside exposure of a Holdgate Sandstone near Baucott, where about 13 ft. of red and green, false-bedded, calcareous sandstone are present. At Kidnall Gutter, Tugford, a section in the '*Psammosteus* Limestone' escarpment gives good exposures in the basal Ditton Series, and reveals some 160 ft. of strata ranging from the uppermost Red Downton marls to the zone of *Pteraspis crouchi* in the Ditton Series. Near the base is the '*Psammosteus* Limestone', about 10 ft. thick, giving rise to a prominent waterfall. Laterally the limestone merges from a massive jointed form into an extremely nodular type some seven yards away. Passing up to the sandstones and cornstones, an account was given of the extremely variable successions encountered in closely-neighbouring stream-sections, and of the origin of the sediments in the Ditton Series. The zone of *Pteraspis leathensis* has been found to be about 50 ft. thick in this section, succeeded by *Pt. crouchi*.

The route from Tugford to Nordybank was made by way of Bouldon and Heathamgate where the party left the coach to climb the bank. The laneside quarry just below Nordybank Camp exposes beds in the lower part of the Clee Series; they are massive, current-bedded, bright red sandstones, which carry bands of marl-pellets, and exhibit 'pepper-pot' markings. These markings are found in the Senni Beds of South Wales, and were demonstrated to the Association by [the late] Mr. W. N. Croft on the field-meeting to Hereford, 1939. At the hillside quarry, once worked for the upper Abdon Limestone, concretionary and fragmental limestone and buff sandstones were examined. From this vantage point the various features of the geology of the western slopes of Brown Clee Hill were pointed out and an excellent panorama of the country to the west was seen.

From Cockshutford a detour was made round the northern end of Brown Clee Hill to Burwarton and Three Horseshoes. The upper part of the Ditton Series cropping out to the east of Three Horseshoes is exposed near Besom Farm and Wheathill. The old quarry, 340 yds. south of east of the farm, reveals coarse yellow cornstones with green calcareous sandstones, and, from near the top, numerous ostracoderm and arctolepid fragments have been obtained. On this occasion Mr. J. L. Hughes found the first cephalaspid known from this horizon; the fossil consists of the greater part of a fairly well-preserved head. Dr. E. I. White writes that it is probably a new genus and appears to be the highest (or youngest) cephalaspid from the British Old Red Sandstone. From this place, the view as far as Sedgely and the Clent Hills was excellent, and Drs. Mitchell and Pocock spoke on the geology of the country to be seen to the east and south.

At Wheathill the party examined further sections in the coarse, buff and purple sandstones and cornstones of the upper Ditton Series. Continuing to Farlow, sections were examined in the Upper Old Red Sandstone. The succession was followed up through the unconformable Carboniferous basal conglomerate—a coarse yellow sandstone with large quartz-pebbles—into the Carboniferous Limestone. From the quarries at Oreton *Syringothyris cuspidata* (Martin), *Camarotoechia mitcheldeanensis* Vaughan, polyzoans and fish teeth were collected, and the various lithologies examined. The structure of the Farlow–Walton ridge was demonstrated.

The route to Clee Hill lay across the heathland of the Catherton Common outcrop of Cornbrook Sandstone and Coal Measures. At the old quarry in the Clee Hill Basalt, Dr. Pocock summarised the difficulties experienced in the interpretation of the nature of emplacement of the Midland basalts. The overlying Coal Measures were observed in the eastern face of the quarry and it was reported that, some months previously, a large xenolith of Coal Measures material had been found in the basalt now worked in the upper part of the quarry. (H.W.B., D.L.D.)

EXPLANATION OF PLATE 11

New excavation in the Comley Breccia (Middle Cambrian) in Hill House Ridge, 660 yds. south of Comley Quarry. The cream-coloured blocks of '*Eodiscus*' *bellimarginatus* Limestone (Lower Cambrian) stand out from the darker matrix as can be seen above, and to the left, of the hammer-head. The smaller white patches, which are distributed throughout the section, are also made of this limestone.

THE CARBONIFEROUS LIMESTONE OF TREAK CLIFF, DERBYSHIRE, WITH NOTES ON THE STRUCTURE OF THE CASTLETON REEF-BELT

By Donald Parkinson, D.Sc., F.Inst.P., F.G.S.

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ABSTRACT.—The Castleton reef-limestones, and particularly those of Treak Cliff, have been re-examined and the conflicting views of the origin and structure of the Castleton Reef-Belt reconsidered. The recently proposed theory that this formation is a combination of flat and apron-reefs is thought to need modification in order to accord with the facts. The reef is considered to have had an original slope towards the basin which was steepened by a temporary uplift in upper D_I times. A later uplift was followed by the deposition of black limestone of P_{Ib} age along the northern margin of the reef.

1. INTRODUCTION

THE Lower Carboniferous reef-limestones of the Castleton area of Derbyshire have been studied and mapped by Shirley & Horsfield (1940) and by the writer (1943, 1947), two different interpretations having been applied to their structure and relation with the adjacent deposits. Recently, in two papers dealing generally with the reef-limestones in the North of England, Bond (1950*a*, *b*) has put forward what is in effect a third interpretation.

Briefly, Shirley & Horsfield's view is that towards the end of Viséan times uplift and erosion of the Derbyshire massif produced cliffs of D_I and D_2 beds, at least 550 ft. high, against which the B_2 reef-limestone was subsequently banked.

The author equates the B_2–lower P_I reef-facies with the D_I–lower D_2 massif-facies, the steeply dipping beds of Treak Cliff and elsewhere being regarded as original accumulations on the outer slope of the reef. The upper D_I reef-limestones and beach-beds are held to be unconformable on middle D_I.

Bond considers that the sloping beds constitute an 'apron' of reef-limestone deposited against a scarp of D_I limestone without much time-interval between the two series. He is in general agreement with the writer and with Hudson (various papers) on the correlation of D_1 and B_2.

The writer's reasons for rejecting Shirley & Horsfield's conclusion have been fully stated (1943, 1947, 1950). More recent work at Treak Cliff, which is reported in the present paper, had caused no more than minor modifications in the interpretation of the stratigraphy when Bond's two papers appeared. The latter author's views are based largely on his own work on the Craven Reef-Belt in the Cracoe area of Yorkshire, but he applies them to the Castleton district, since the two regions have much in common, and he has further had the advantage of being taken over the ground by Shirley. It is part of the purpose of the present paper to re-examine the evidence in the light of the third interpretation of some of the important features of the Castleton Reef-Belt.

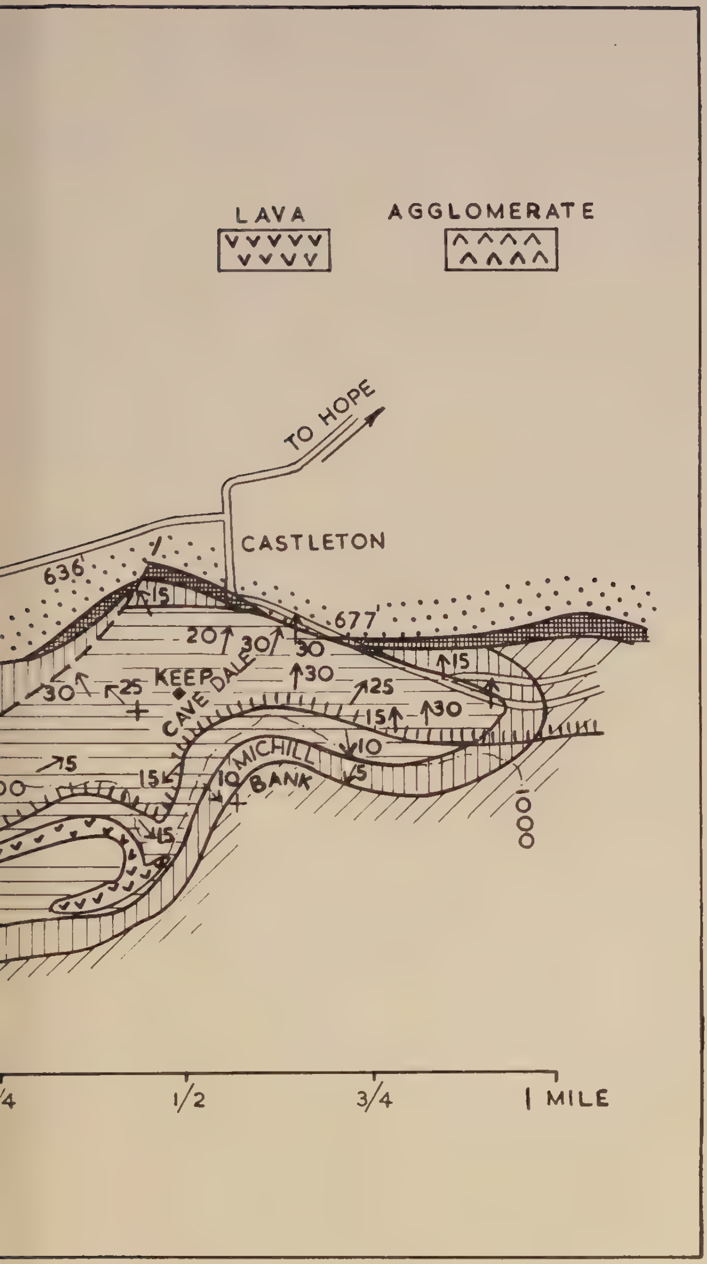
The map (Fig. 1) covers most of the ground included on an earlier map (Parkinson, 1947) and a small area to the west of it, but the upper B_2 beds are now introduced as a separate sub-division. Otherwise the map is simplified following criticisms that parts of the original map were difficult to interpret without colour.

Thanks are due to Mr. W. S. Bisat for identifying the goniatites, to Mr. A. Ludford for help in the topographical survey of Treak Cliff and to Mr. H. R. Willcocks for re-drawing the author's rough diagrams.

2. THE REEF-LIMESTONE OF TREAK CLIFF

(a) **General features.** Treak Cliff has been studied in varying degrees of detail by several workers, including Jackson (1927, 1941), Alexander (unpublished), Shirley & Horsfield (1940), Hudson & Cotton (1945*a*, *b*), Parkinson (1947) and Bond (1950*a*, *b*). This is not surprising in view of the highly fossiliferous nature of the brachiopod-beds of B_2 age of the northern and north-eastern slopes, but at the same time the difficulty of determining the details of their sequence and their relationship with the D_1 limestone forming the north–south summit-ridge and the flat to the west of it. What is, perhaps, more surprising is that a comprehensive faunal list has not yet been published, although the more important horizon-markers have been recorded in one or other of the papers cited above.

The map (Fig. 2) was produced on the 25 inch to a mile scale, but its accuracy is not quite in keeping with the large scale employed since the position of some of the exposures has proved difficult to fix and the contours cannot claim to be correctly placed. They were drawn initially by magnification from the 2½ inch to a mile map and it was immediately obvious that, near the top of the hill, they bore no relation to reality. They were largely re-drawn following a rough survey of the ground with an altimeter, a procedure liable to error even when the barometric changes


LAVA
AGGLOMERATE
TO HOPE
CASTLETON
636
677
KEEP
CAVE DALE
MICHILL
BANK
1000
15
20
30
30
30
25
25
30
15
30
15
10
15
10
5
15
15
1/2
3/4
1 MILE

[To face p. 252

are small, as was actually the case when the observations were made. However, the survey has helped to make a little clearer some of the details of the sequence.

(b) **The Middle D_I Beds.** The summit ridge of Treak Cliff and part of the flat to the west of it are occupied by generally sparsely fossiliferous reef-limestones with little or no dip. On the east side of the ridge the dip changes abruptly to 30–35° ENE. about 70 ft. below the top of the hill. The steeply dipping beds are inclined on the average at nearly the same angle as the average slope of the ground and therefore the beds at the bottom of the eastern slope of the hill, near the unconformable junction with the Edale Shales, are a little older than those at the top, assuming a normal relation between the horizontal and dipping beds. Northwards from the ridge the beds apparently remain flat to a point beyond the *Dielasma* Bed (Locality 1 on the map, Fig. 2) and then assume a northerly dip which, below the erosion-surface (described below) at the point X on the map, is about 15°. It is estimated that the beds immediately below this break in the sequence, which is taken for reasons given below as the boundary between middle and upper D_I (B_2), are rather lower than those at the top of the ridge. There are thus on Treak Cliff about 70 ft. of beds constituting the upper part of middle D_I. Lower beds come to the surface a little to the south in the gorge of the Winnats.

Diagnostic fossils in the horizontal and gently dipping beds include the corals *Dibunophyllum bourtonense* Garwood & Goodyear and *Palaeosmilia murchisoni* (Edwards & Haime) and the brachiopod *Davidsonina septosa* (Phillips). The latter form is characteristic of the top of middle D_I and probably the lower part of upper D_I. Reef-brachiopods abound in the *Dielasma* Bed (Parkinson, 1952) where, from a thickness of less than one foot, more than 475 specimens of *Dielasma hastata* (J. de C. Sow.), 200 specimens of *Schizophoria resupinata* (Martin) and large numbers of other brachiopods have been collected. Recently more of the bed has been exposed and it is now found to be thicker than was at first thought. Actually it is a shell-pocket in approximately horizontal and obscurely bedded limestone some 60 ft. below the top of the ridge. It has yielded the following brachiopods, but no goniatites:

Brachythyris pinguis (J. Sow.)
Camarotoechia triplex (M'Coy)
Dictyoclostus hindi Muir-Wood
Dielasma hastata (J. de C. Sow.)
Echinoconchus elegans (M'Coy)
E. punctatus (J. Sow.)
E. subelegans (Thomas)
Eomarginifera triquetra Muir-Wood
Gigantoproductus edelburgensis (Phillips)
G. sp.

Krotovia aculeata (J. Sow.)
K. spinulosa (J. Sow.)
Leptaena cf. *analoga* Phillips
Linoproductus corrugatus (M'Coy)
Martinia cf. *glabra* (J. Sow.)
Overtonia fimbriata (J. de C. Sow.)
Phricodothyris lineata (J. Sow.)
Plicatifera plicatilis (J. de C. Sow.)
Productus concinnus J. Sow.
P. productus (Martin)
Pugnax pugnus (Martin)
P. reniformis (J. Sow.)
P. sp.
Reticularia aff. *acutiloba* George
Rhipidomella michelini (Leveillé)
Schizophoria resupinata (Martin)
Spirifer attenuatus J. de C. Sow.
S. bisulcatus J. de C. Sow.
S. duplicicostus Phillips
S. cf. *grandicostatus* M'Coy

The steeply dipping beds of the eastern slope are considered to have accumulated on the outer slope of the reef. They contain many brachiopods, but not nearly in such abundance as the upper D_1 beds of the north bluff. Occasional corals are seen, particularly *Lithostrotion* spp. These outward dipping deposits have every appearance of normal sediments and do not in general indicate a talus-slope, though doubtless some of the material is derived from the more elevated levels of the reef. Brecciation is on a small scale.

(c) **The Upper B_2 Beds.** These deposits constitute the well-known brachiopod beds of the northern and north-eastern slopes of Treak Cliff. They apparently lie on an eroded surface of the middle D_1 reef-limestones. Only at one locality on Treak Cliff itself (in the crag marked X in Fig. 2), where it was first observed by Shirley & Horsfield (1940; see also Parkinson, 1947), has this erosion-surface been clearly seen, though possibly there are suggestions of it near Locality 3. For a distance of a few yards at X very friable brachiopod and crinoidal reef-limestone is seen above an irregular surface containing shallow potholes of less fossiliferous and more compact reef-limestone with layers of reef-tufa. The beds below the hiatus dip at a lower angle than those above it. The upper part of the exposed boundary is steeply inclined and, for a few feet at least, the upper beds may be said to be banked against the lower. Farther down the cliff the line of junction appears to be much less steeply inclined. The whole exposure, however, is too small for it to be employed as providing an estimate of the dip of the original surface even assuming no subsequent tilting. West of the point X the boundary between middle and upper D_1 (B_2)

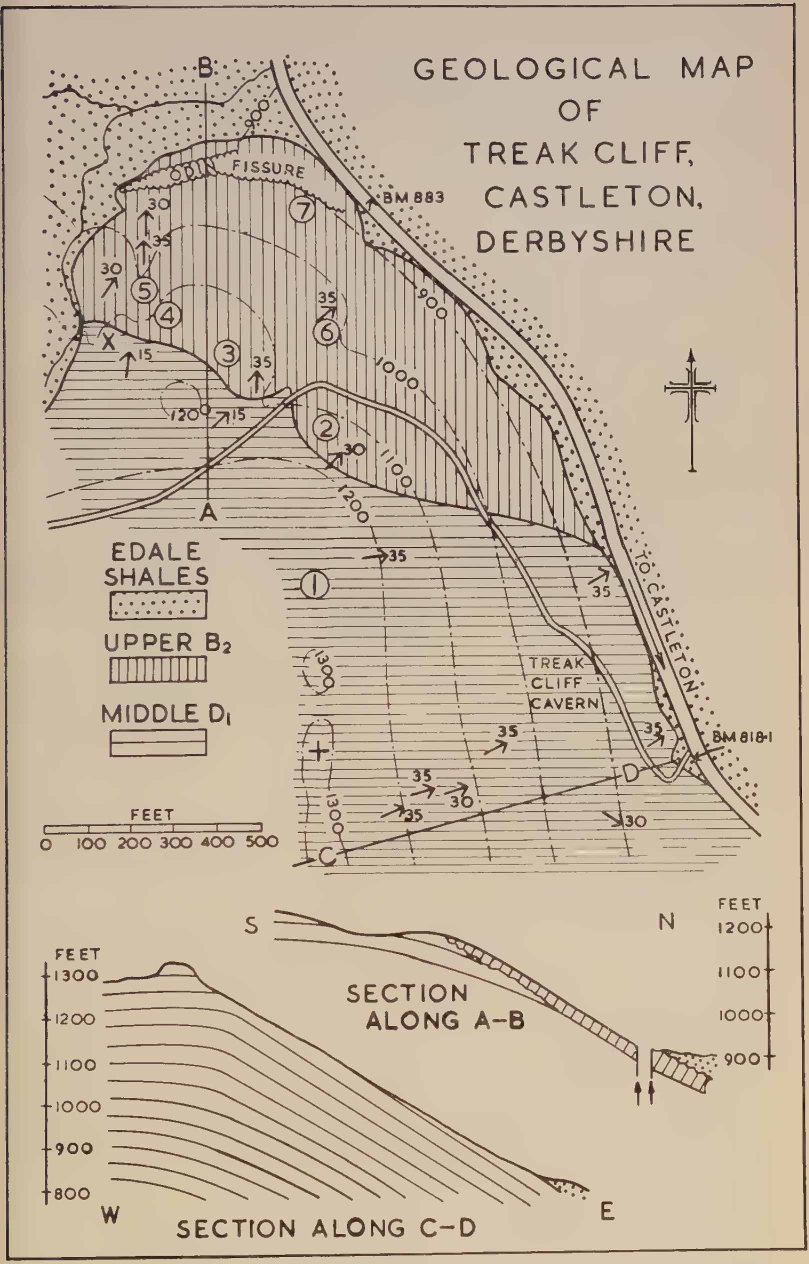


Fig. 2. Geological map and sections of Treak Cliff near Castleton, Derbyshire

passes beneath the unconformable cover of Edale Shales. To the east it is presumed to follow the line indicated on the map, though the actual position where it follows down the slope is problematical.

The upper B_2 brachiopod-beds appear to be less than 50 ft. thick (see section in Fig. 2). They are mainly highly fossiliferous white or light grey reef-limestones, often very shelly and sometimes highly crinoidal. Darker, partly brecciated, beds occur at the top of the series near Odin Fissure and in the middle of the group is a bed of dolomite. Next to brachiopods, molluscs are the commonest fossils and some were recorded by Jackson (1927). Corals are less frequently seen than is usual in reef-limestones of the D Zone. The characteristic reef form, *Amplexus coralloides* J. Sow., occurs sparingly and one specimen, probably referable to *Dibunophyllum bourtonense* Garwood & Goodyear, has been seen, together with occasional *Lithostrotion* spp. and fragments of other corals. Shirley & Horsfield (1940) cite the D_2 coral *Palaeosmilia regia* (Phillips). Hudson & Cotton (1945*a*) refer to several species collected by G. B. Alexander, some of which, including the D_2 form *Lonsdaleia duplicata* (M'Coy), may have come from the beds under consideration.

Brachiopods collected by the writer are listed below. The positions of Localities 2 to 6 are indicated in circles on the map (Fig 2.) Other exposures on the north bluff are collectively denoted by the numeral 8. Further collecting would doubtless add considerably to the list.

BRACHIOPODS	LOCALITY NUMBERS
Actinoconchus planosulcatus (Phillips)	2, 3, 5, 6
Athyris expansa (Phillips)	8
A. lamellosa (Leveillé)	2, 6
Avonia youngiana (Davidson)	2, 4, 6, 8
Brachythyris integricosta (Phillips)	2, 6, 8
B. planicosta (M'Coy)	8
B. pinguis (J. Sow.)	2
Buxtonia scabricula (J. Sow.)	4, 6, 8
Camarotoechia pleurodon (Phillips)	2, 3, 4, 5, 6, 8
C. (?) *trilatera* (de Koninck)	5
C. triplex (M'Coy)	2
Cliothyridina globularis (Phillips)	3, 6
Dictyoclostus antiquatus (J. Sow.)	2, 6, 8
D. hindi Muir-Wood	4, 6, 8
D. insculptus Muir-Wood	8
D. multispiniferous Muir-Wood	4
D. muricatus (Phillips)	4
D. sulcatus (J. Sow.)	4, 6
Dielasma hastata (J. de C. Sow.)	2, 3, 4, 5, 6, 8
Echinoconchus elegans (M'Coy)	3
E. eximius (Thomas)	6
E. cf. *eximius* (Thomas)	2
E. punctatus (J. Sow.)	3, 6, 8

E. subelegans (Thomas)	8
E. venustus (Thomas)	4, 6, 8
Eomarginifera triquetra Muir-Wood	2, 3, 5, 6, 8
Krotovia aculeata (J. Sow.)	2, 6, 8
K. spinulosa (J. Sow.)	2, 3, 6, 8
Leptaena cf. *analoga* Phillips	2, 8
Linoproductus undatus (Defrance)	6
Martinia glabra (J. Sow.)	6, 8
M. cf. *glabra* (J. Sow.)	2, 3, 6, 8
Overtonia fimbriata (J. de C. Sow.)	2, 3, 4, 5, 6, 8
Phricodothyris lineata (J. Sow.)	2, 4, 5, 6, 8
Plicatifera carringtoniana (Davidson)	8
P. mesoloba (Phillips)	6, 8
P. plicatilis (J. de C. Sow.)	2, 3, 4, 5, 6
Proboscidella proboscideus de Verneuil	8
Productus concinnus J. Sow	3, 6
P. productus (Martin)	2, 8
Pugnax acuminatus (J. Sow.)	3, 8
P. pugnus (Martin)	2, 3, 4, 6, 8
P. reniformis (J. Sow.)	3, 8
P. sp.	2
Reticularia acutiloba George	3
R. imbricata (J. Sow.)	2, 6
Rhipidomella michelini (Leveillé)	4
Schizophoria palliata Demanet	2, 5
S. resupinata (Martin)	2, 3, 5, 6, 8
Spirifer bisulcatus J. de C. Sow.	2, 3, 4, 5, 6, 8
S. duplicicostus Phillips	3, 8
S. cf. *plicatosulcatus* North	5
S. cf. *rhomboideus* Phillips	3
S. cf. *semicircularis* Phillips	6
S. striatus (Martin) group	2, 6, 8
Spiriferellina insculpta (Phillips)	4, 8
S. octoplicata (J. de C. Sow.)	3
S. perplicata North	4
Syringothyris cuspidata (J. Sow.)	6, 8
Tylothyris subconica castletonensis North	2, 4, 8

The number of goniatites collected during the course of this work has been disappointingly small. Locality 5, in the lower part of the series, has yielded *Beyrichoceras micronotum* (Phillips) group (with strong *constrictions*) and *Nomismoceras* aff. *vittigerum* (Phillips). At a higher horizon (Locality 6), a prominent crag on the lower part of the north slope *Goniatites crenistria* Phillips (group) has been found and, still higher, though probably by no more than a few feet, at Locality 7, near Odin Fissure, occurs an association of *Goniatites crenistria* group (possibly *G. wedberensis* Bisat or a near ally) and *Beyrichoceratoides truncatum* (Phillips) group. Species not precisely localised include *Dimorphoceras* sp. and *Goniatites* sp. with strong constrictions and one specimen with spirals.

Goniatites previously recorded from Treak Cliff which may include specimens from middle as well as upper D_I include *Beyrichoceras castletonense* Bisat, *B. delicatum* Bisat, *B.* cf. *excavatum* (Phillips), *B.* aff. *phillipsi* Bisat and *Goniatites* cf. *hudsoni* Bisat.

Bisat considers the beds of Locality 7 to be rather lower than the base of P_{Ia}, which is characterised by an association of *G. crenistria* and *B. truncatum*, and it now seems possible that the Odin Beds are just below the top of B_2. The author, following Hudson & Cotton (1945*b*), formerly referred them to basal P_{Ia}.

The present investigation has provided little new evidence on the question of the detailed correlation of the coral and goniatite zones. The brachiopods in the upper B_2 limestones do not seem to include any forms not known below D_2, but the records of *Lonsdaleia duplicata* M'Coy and *Palaeosmilia regia* (Phillips) suggest that the top of D_I may have to be fixed rather lower than the top of B_2.

3. APRON-REEFS

According to Bond an 'apron-reef' consists of a core of reef-limestone or limestone of massif-facies, an erosion-surface, probably along the line of a fault or fault-scarp, and an 'apron' which might consist of scree material derived from the scarp, freshly accumulated sediment or a mixture of both. In his descriptions of apron-reefs, Bond has amplified some of the ideas of Hudson, who first used the term 'reef apron' (1930–1). Hudson & Cotton (1945*a*), in fact, in a description of the Alport boring, produce a sedimentation diagram which shows the brachiopod-beds of Treak Cliff dipping steeply against, and in apparent unconformable relationship with, the comparatively horizontal limestone of the massif. This diagram also shows a pre-upper B_2 fault which the authors state represents the movement that initiated the slope on which the shell-reef limestone (brachiopod-beds) were formed. The authors also suggest that the movement (together with later manifestations of it) included both faulting and monoclinal folding. Hudson & Cotton's fault is shown to throw down to the north and Bond (1950*a*, p. 319) in fact postulates a north-facing scarp 'probably produced by a fault with a downthrow to the north, formed in late Lower Carboniferous times. Reef-limestone facies rests on this scarp-slope, very much as talus lies on the slope of a modern hillside. This facies probably accumulated as a kind of submarine scree, with initial dips up to 45°. Thus there is a pronounced discordance between the bedded limestone-core and the talus material lying on it.'

In order to test the validity of Bond's hypothesis, it is first necessary to try to find the position of the alleged fault and the configuration of the resulting fault-scarp when the brachiopod-beds were laid down in front of it. As regards the fault itself, it is difficult to find direct evidence of its existence and if present it is buried as indicated in Hudson & Cotton's diagram. Its probable location on Treak Cliff is the erosion-surface (X on Fig. 2). It is evident from the map (Fig. 2) that a buried east–west fault passing through this point is unlikely to be proved at the surface elsewhere. It is necessary to try to trace the line of the resulting fault-scarp by consideration of the surface dips. This involves separating the original dips from the tectonic dips. The map (Fig. 1) shows that the beds of massif-facies rarely dip at angles greater than 5°. Substantially they may be taken to be horizontal, although at a few places, near the boundary with the reef-limestone, that is at the margin of the stable area, they have higher local dips in different directions. The dips in the reef-limestone are highest on the outer slopes. Some of these dips may be tectonic, some may be original and some a combination of the two. The writer knows of no infallible test for distinguishing between them. For the present purpose the anomalous local dips will be ignored and it will be assumed that all other dips in the reef-limestone are original. Towards the boundary of the unconformably overlying Edale Shales, the dips in the reef-limestone sometimes change abruptly and, as stated by Shirley & Horsfield, they point away from the massif at fairly high angles. A line drawn through the points where this change of dip is actually seen on the ground should give us the approximate position of the fault-scarp or erosion-surface, on which these peripheral beds were laid down.

A study of the dips on the map (Fig. 1) shows that such a line would run north-eastwards from Snelslow to Treak Cliff where it would turn abruptly south-south-eastwards past the Winnats to Cow Low. It would then turn north-eastwards towards Castleton and, finally, to the east-south-east. Such a line bears little resemblance to a fault-scarp unless it were a deeply dissected one resulting from a long period of erosion and probably sub-aerial denudation, which would favour Shirley's, rather than Bond's, hypothesis. Bond's conception of an apron-reef does not involve more than a minor hiatus between the formation of the core and the apron, and in fact he refers to the unconformity as a deceptive one. His views necessitate the simultaneous formation of core, scarp and apron. In a sketch (1950*b*) through Elbolton in the Craven Reef Belt his apron-reef beds rest on both D_1 and S_2 limestones, which means, in the absence of a major unconformity, that they began to form before D_1 times.

An essential feature of Shirley's theory is the presence of the pre-B_2 cliff which is regarded by him as representing the coast-line of the period (1940). Bond accepts the existence of this cliff since he states (1950*b*, p. 273) that 'at Castleton, for instance, the exposed relief of the erosion slope is of the order of 550 feet'. His interpretation differs from Shirley's in the suggestion that the cliff-line is near sea level. Shirley apparently bases his height of 550 ft. on the difference in altitude between the top of

Treak Cliff and the Edale Shales at the bottom and the fact that B_2 reef-limestone covers the slope.

Both Shirley and Bond suggest that the steeply dipping reef-limestones are in the nature of scree deposits. It happens that, both on the north and east slopes of Treak Cliff reef, breccia or conglomerate is uncommon and such as is present can be seen in any normal reef-limestone. This of course does not invalidate the apron-reef theory, but it suggests that the sediments for the most part are substantially in their original position.

4. THE BEACH-BED AND ASSOCIATED DEPOSITS

Any satisfactory interpretation of the structure and history of the Castleton Reef-Belt has to take account of the beach-bed first described by Barnes & Holroyd (1896). This deposit is found on the lower slopes of both sides of the Winnats and in several exposures near the bottom of the dip-slope of limestone between the Winnats and Castleton. It consists of several feet of well-bedded limestone incorporating innumerable water-worn shell and crinoidal débris and many broken and rounded brachiopod valves, particularly of large *Producti*. As typically developed it has not the character of a normal reef-breccia or conglomerate and can hardly be interpreted as scree- or talus-material merely broken off and reconsolidated from a growing reef. It rather suggests, as the name implies, wave-action against a shoreline. Barnes & Holroyd postulated such a shoreline to the north, a conclusion which the writer's work seemed to support (1947), it being suggested that the beach-bed might have formed against the reef which had been uplifted along an east–west line passing through Treak Cliff. On such a view the upper D_1 shell-reef beds accumulated on the eroded surface along the north side of the upraised reef and the beach-beds along the south side. A similar explanation was offered by Hudson & Cotton (1945*a*, p. 309) but the uplift was postulated to follow the deposition of the upper D_1 beds. The implications of the present author's theory were not discussed fully; one of them is that the reef extended some distance north of its present position at Cow Low and, therefore, the steeply-dipping beds on the eastern slope of Treak Cliff and the northern slope of Cow Low could not be regarded as deposits originally forming the reef-front as is now assumed following more recent work. Another is that the high dips of the beach-beds at the Winnats would have to be regarded as tectonic. Either explanation seems to demand the emergence of the reef some hundreds of feet above sea level.

The beach-bed series, which includes semi-reef limestones and also thin tuff beds and tuff-bearing limestones, was correlated by the writer (1947) on both field evidence and on the resemblance of the beach-bed itself to the tuff-bearing conglomerate of Cave Dale, which is of proved upper D_1

age. The group as a whole can hardly be higher than low D_2 (P_{Ia}) since near Castleton it underlies, apparently unconformably, black limestones of probable P_{Ib} age (Parkinson, 1947).

5. THE UPPER D_I EARTH-MOVEMENT

Despite Bond's suggestion that the unconformity is a deceptive one the writer considers that no reasonable interpretation of the facts is possible on the assumption that deposition was more or less uninterrupted throughout the duration of time represented by the *Dibunophyllum* Zone. Shirley & Horsfield (1940) adduced evidence for an unconformity above the Cave Dale lava in upper D_I; they called attention to erosion-surfaces on Treak Cliff, Windy Knoll and elsewhere and showed the beach-beds, which they correlated with the Nun Low limestone, to be unconformable on the B_2 reef-limestone. The present author (1947) argued that these phenomena were all manifestations of the same earth-movement, a movement which was initiated in upper D_I times. The further study has been directed to determining more precisely the nature of the unconformity and the surface on which the newer rocks were deposited. On the massif itself the near-horizontality of the bedding and the absence of major faulting (the faults shown do not seem to extend beyond the marginal area) are factors suggesting a simple approach to the problem, provided a bed close to the hiatus can be located over a sufficiently wide area. Such a bed is the oolitic conglomerate of Windy Knoll which, on field evidence and lithology, has been correlated (Parkinson, 1947) with the tuff-bearing conglomerate of Cave Dale and the beach-bed of Castleton. South of Windy Knoll there are three exposures of this bed near Oxlow House, two in the reef-facies and one in the massif-facies at altitudes ranging between 1360 and 1390 ft. O.D. The altitude decreases fairly uniformly in successive exposures in an easterly direction until on Michill Bank it has fallen to 1000 ft. The section on Michill Bank is almost due east of that south of Oxlow House and they are both in the massif-facies immediately south of the transition to reef-limestone. The oolitic and pebbly nature of this deposit indicates deposition in very shallow water and suggests fairly uniform conditions over a stretch of at least $1\frac{1}{3}$ mi. along the boundary of reef and massif. About 10 ft. below this bed in Cave Dale and 20 ft. above the lava is a bed referred to by Shirley & Horsfield as containing D_I corals. The position of the unconformity itself is probably below the coral-bed since the latter can be traced along the hillside in the direction of Michill Bank, where it is partly brecciated and contains broken and worn *Productus* valves (Parkinson, 1947). There is also a bed on Michill Bank above the tuff-bearing conglomerate composed of the broken-up valves of large *Producti*. The indications are that the tuff-bearing conglomerate and associated deposits accumulated on a surface which, along much of the boundary between reef and massif, was fairly uniform. The present height of the surface falls nearly 400 ft. between Oxlow House and Michill Bank, which can be accounted for by a later tilt of less than 3°E.

West of Oxlow House conditions were rather less uniform. Shirley & Horsfield (1940, p. 290) call attention to 'Neptunean dykes in a promontory of D_1 limestone against both sides of which were banked breccia or knoll-reef limestone' in Windy Knoll quarry. The difference between the author's and Shirley's interpretation is in the duration of time between the erosion of the D_1 limestone and the filling of the fissures with reef-limestone. This may not have been long, since the cavities are not more than a few feet deep, and there is no reason to believe that the upper beds are later in age than upper D_1. The lower beds contain *Davidsonina septosa* and are therefore no lower than high middle D_1. There is no exposure of the oolitic conglomerate here, its position being probably a little above the highest beds seen.

Along the line parallel to the trend of the reef-belt there is apparently no pronounced overstep either towards the east or the west, the upper D_1 beds lying on beds normally little below them in the succession. Evidence of overstep *across* the reef-limestone has been adduced (Parkinson, 1947) and this aspect of the problem will now be considered in more detail. On Michill Bank the tuff-bearing conglomerate and associated broken shell beds pass under higher strata towards the east. These low D_2 beds, according to the author's interpretation, assume a shelly reef-facies on the north-facing slope of Michill Bank west of the entrance to Pin Dale (at the eastern extremity of the map, Fig. 1) and along the line of the reef-belt. Upper D_1 beds appear again in Pin Dale and include the coral-bed which in Cave Dale is a little below the tuff-bearing conglomerate and which in Pin Dale itself contains rolled material, including lapilli. It is to be expected, therefore, that on Michill Bank the tuff-bearing conglomerate with its shelly limestone band should pass down the slope west of the D_2 reef-beds as basal members of the upper D_1 reef-beds. Exposures are too scanty for these deposits to be followed down the hillside, but shelly limestones, including conglomeratic beds, rest on reef-limestone on the lower slope of the hill. It seems highly probable that these beds are equivalent to the tuff-bearing conglomerate, although they are not oolitic. They form the eastern extension of the beach-bed series (Parkinson, 1947). Differences in facies between the beach-beds and the tuff-bearing conglomerate are to be expected from the position on opposite sides of the reef-belt despite the fact that the latter is very narrow. The differences consist in the apparent absence of diagnostic corals and oolitic grains in the beach-beds, the resemblances in the presence of water-worn shells and volcanic tuff in both series.

Previous estimates (Parkinson, 1947) of the extent of overstep of the tuff-bearing conglomerate beach-bed series over the reef-limestone ranged from 50 ft. at Castleton to 200 ft. at the Winnats. More recent estimates based on somewhat different reasoning have roughly confirmed the former figure. Thus the thickness of reef-limestone in Cave Dale between the *pugnus*-bed near the valley-floor and the entrance to the dale is approximately estimated as 150 ft. From the *pugnus*-bed up the hillside to Michill Bank the thickness of reef-limestone is probably rather more than 150 ft., and it is followed by 75 ft. of bedded limestone before the coral-bed marking the approximate base of upper D_I (and a few feet below the tuff-bearing conglomerate) is reached near the top of the bank. At the mouth of Cave Dale the beach-beds are cut out by the overstep of the P_{Ib} black limestones. A little to the east the P_{Ib} beds are themselves transgressed by the Edale Shales, and if the author's interpretation is correct (Fig. 1), three unconformities have here merged into one. The overstep of the P_{Ib} beds has evidently not cut down much below the base of the beach-beds, which it is estimated would otherwise have lain on reef-limestones some 150–175 ft. above the level of the *pugnus*-bed. Since on Michill Bank the coral-bed below the conglomerate is at least 225 ft. above the *pugnus*-bed, it is evident that, unless the original thickness of the reef-limestone differed in the two directions considered, there is an overstep of upper D_I over middle D_I to the north of 50–75 ft. in a horizontal distance of 1000 ft.

It is, of course, true that individual beds of reef-limestone do not maintain a constant thickness and it could be argued that in the vicinity of Castleton the apparent overstep is accounted for by thickness changes, but such changes are not apparent and are difficult to prove indirectly because of the facies-changes. But at the Winnats it is difficult to account for the phenomena observed other than by overstep of the beach-beds across the reef-limestone in a north-easterly direction. Here thin-bedded limestone with abundant rolled shell-fragments, including many large *Producti*, clearly lie with a dip of 30–35° on reef-limestone with a similar average strike, but with dips ranging from 15 to 25°, with a local dip of 30° at the mouth of the gorge on the south side. The beach-beds on the north side of the gorge are exposed over much of the ground up to an altitude of 1000 ft. The reef-limestones locally contain *Gigantoproductus* in greater abundance than usual, thus providing much of the material incorporated in the beach-beds. It was formerly suggested (Parkinson, 1947) that the reef-limestone forming the crags at the top of the Winnats was at least 200 ft. higher in the sequence than that immediately below the beach-beds at the mouth of the gorge. Additional measurements of dips in the reef-limestone suggests the figure of 200 ft. to be high, a more probable estimate being 150–175 ft. But, as has frequently been said, estimates of the thickness of reef-limestones from considerations of the dip are liable to considerable error, since the angles of inclination are very rarely well-defined and often the rocks are quite unbedded. (In a cliff, high on the slope of the Winnats near the entrance on the south side, a few feet of reef-limestone displays surfaces inclined at 60–70° having the appearance of bedding planes.)

The beach-beds are presumably overstepped by the Edale Shales along the foot of the eastern slope of Treak Cliff. On the north side, according to the writer's interpretation, they are replaced by the upper B_2 shell reef-limestones, the irregular base of which, seen at X in Fig. 2, has been shown to be on rocks equivalent in age to those of the summit ridge. The latter contain *Davidsonina septosa* and the hiatus here may be small, but it seems likely that it increases down the slope to the north. That the overstep extends down the hill can be inferred but its magnitude cannot be determined in the absence of exposures in the lower series of beds. (See north–south section in Fig. 2.)

The above reasoning seems to show that, in the back-reef and flat-reef areas, erosion accompanying the earth-movement was inconsiderable but that it increased down the outer slopes of the reef. The erosion seems in general to have had the effect of steepening the original reef-front, but it probably did not change the configuration very much, or in other words the overstep was down the front of the reef and perpendicular to its trend. The surfaces on which the upper D_I reef-limestones, including the beach-beds, were deposited was inclined at an angle of 30 to 35°. The dip of the reef-front before the uplift seems to have varied between 15 and 30° with an average of the order of 20°. It is difficult to account for the phenomena observed except on the hypothesis of a vertical uplift of some magnitude, since the beds, which suffered the most erosion, were apparently those which, prior to the uplift, occupied the reef-front at a depth of some 350–400 ft., and these would have to be brought within the reach of wave-erosion. North-east of the boundary with the reef-limestone near the Winnats the dip of the beach-bed series shallows considerably and this may indicate an approach to the outer margin of the reef. Near Castleton basin deposits of P_{Ib} age lie unconformably on the beach-beds and reef-limestone (Parkinson, 1947) along the northern margin of the reef, suggesting possibly that the original limit of the latter may not have extended far beyond the existing boundary.

In Fig. 3 an attempt is made to reconstruct the surface on which the upper D_I reef-limestones, including the beach-beds, were deposited. The nature of the reef-front with any irregularities smoothed out is indicated by contours drawn at 100-ft. intervals. The outer and lower limits cannot be proved in the absence of exposures but it is thought to be unlikely that the reef-front anywhere exceeded 550 ft. in altitude. In Fig. 3 is also drawn the probable position of the inner margin of the reef,

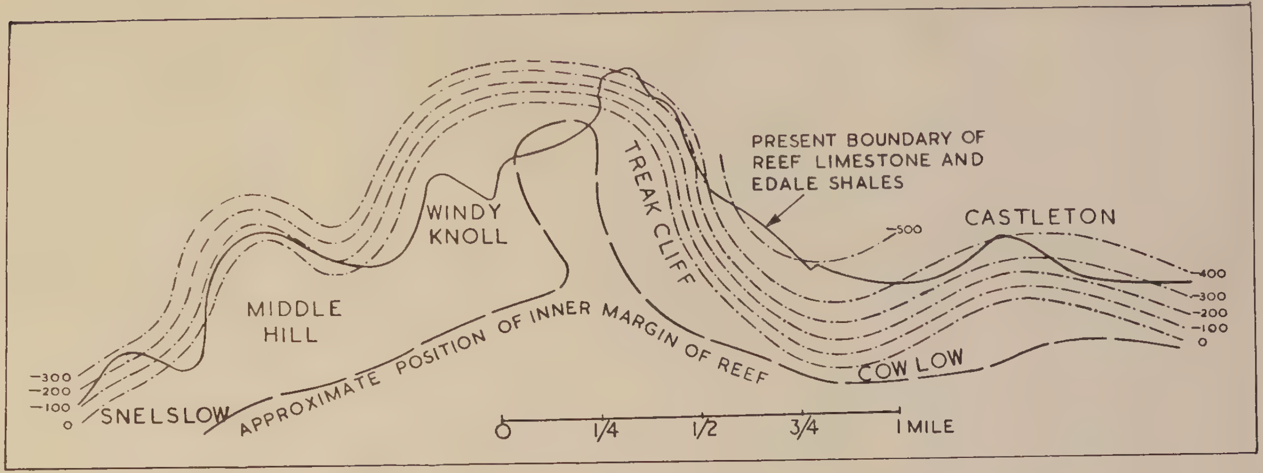


Fig. 3. Reconstruction by means of contours drawn at 100-ft. intervals on the reef-front of the surfaces on which the upper B_2 reef-limestones and beach-beds were deposited

a line which is substantially that existing at the present day. The position of the unconformable junction of the limestone with the Edale Shales is also indicated.

6. MODE OF ACCUMULATION OF THE MARGINAL REEF

We now have to consider the conditions of deposition of the D_1 reef-limestone before the upper D_1 movement. Except near Cow Low Nick there is a variable, though never wide, strip of relatively flat reef between the massif-facies and the top of the outer reef-slope. It seems reasonable to postulate growth of the reef both upwards and outwards (towards the basin) and possibly sometimes inwards (there are dips towards the massif in Cave Dale and Middle Hill), according to the relative rates of subsidence of the massif and basin areas. There would soon be produced, it is thought, a slope towards the basin by down-warping and this would tend to increase both in height and steepness because of the more active organic growth at the higher levels. At the lower levels the slope would be extended partly by organic growth and partly by sediments derived from the upper levels of the reef, somewhat as envisaged at the present day on the seaward slope of the Bikini Atoll (Ladd *et alia*, 1950). Such conditions of deposition imply that the dipping beds are not just a skin on the surface as envisaged by Bond's hypothesis but that they continue through much of the thickness of reef-limestone. The dip, however, under uniform conditions of sedimentation would be expected to diminish towards the basal beds of the reef as is shown in the east–west section through Treak Cliff in Fig. 2. This diagram, admittedly simplified, indicates both outward and upward growth and shows that the sediments are likely to be rather thicker through the advancing position of the top of the reef-front than elsewhere.

Although such a theory is difficult to prove, actual observations on the ground do not appear to conflict with it. In the gorges of Cave Dale, Peak Cavern and the Winnats, the dips (assumed, of course, to be original) tend to increase down the valleys towards the higher beds in keeping with expectations.

7. GENERAL CONCLUSIONS

A completely satisfactory interpretation of all the features observed in the Castleton reef-limestones and associated beds has, in the writer's view, not yet been achieved and it is not claimed that the further work discussed here has solved all the problems. The assumption, for example, that the dips in the reef-limestone are substantially all original may not be fully justified. Nevertheless it is hoped that the conclusions reached will help to reconcile some of the conflicting views which are at present held on a puzzling bit of country.

The theory presented here postulates vertical uplift along the boundary of the stable and unstable areas at a time when the bottom of the reef-front was a few hundred feet—in places as much as 500—below sea level. This would have the effect of producing an elevated area—for the most part plateau—of limestone with a steeply sloping shoreline. Most of the erosion would be marine, the effect of sub-aerial denudation being small. The uplift was shortlived, and, as the ground sank again, the beach-beds were formed in the bay between Treak Cliff and Michill Bank. At the same time the shell-reef limestone accumulated on the sinking promontory of Treak Cliff. The oolitic and tuff-bearing conglomerate-episode would occur when the edge of the massif had finally sunk below sea level.

A later earth-movement, probably of a similar character, was followed by the deposition of the $P_{\mathrm{I}b}$ black limestones along the margin of the basin. A discussion of the precise equivalents of these beds in the back-reef areas is outside the scope of this paper, but they are thought to be not higher than D_2 (see Hudson & Cotton, 1945*a*). Within the area under consideration all beds higher than middle or higher P_{I} are cut out by the overstep of the Edale Shales which form an overlapping series on the Carboniferous Limestone. The work of Hudson & Cotton on the Edale and Alport borings shows that the unconformities fill in rapidly towards the north and that the succession soon becomes fairly complete.

Since this paper was first drafted, T. D. Ford (1952) has described the underground geology of the Castleton district. He finds evidence of a gradual transition between the massif- and reef-facies and shows that the steep outward dips of the reef-facies decrease gradually towards the horizontal or low-dipping massif-facies. These observations and Ford's general conclusions are fully in accord with those of the author.

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THE WIVELSFIELD SAND

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ABSTRACT.—The paper discusses the age of a ridge of sandstone in central Sussex. Its relations with surrounding rocks are puzzling and previous writers have seen it as Tunbridge Wells Sand age, and explained its position by abnormal deposition or trough-faulting. Detailed 6 in. to the mile mapping with mechanical analyses of the sand and sandstones indicate that it is of Weald Clay age, and that dip-faulting of considerable magnitude has brought it into juxtaposition with members of the Tunbridge Wells Sand series.

1. INTRODUCTION

IN the summer of 1951, the writer proposed to the Geology Class, meeting under the Joint Committee of Adult Education in Worthing, that it should attempt the solution of some local geological problem. He suggested that the age of the Wivelsfield Sand, a rounded ridge of which crosses the main London–Brighton railway, 2½ miles south of Haywards Heath, offered ample scope. It was easily accessible and linked up with the lecturer's own work on the sub-division of the Weald Clay (Reeves, 1948). Bad weather curtailed the field work of the class, so the writer completed the work alone and offers the following solution.

2. PREVIOUS WORK

The Wivelsfield Sand was originally mapped by W. Topley (1875, p. 98), who was clearly puzzled by its relations with the neighbouring rocks. Stating that it was 'mapped with care', he concludes, 'it joins on to the great mass of the Tunbridge Wells Sand' yet apparently he regarded the clays, which outcrop to the north and south of it, as Weald Clay. He therefore suggested that the Wivelsfield Sand is of Tunbridge Wells Sand age, but *underlain* by Weald Clay.

3. POSSIBLE SOLUTIONS

(a) **Trough-faulting.** The difficulty of having this tongue of Weald Clay to the north of the Wivelsfield Sand and still regarding the latter as of

Tunbridge Wells Sand age, was commented upon by H. J. Osborne White (1924, p. 12), and he suggested the possibility of trough-faulting. The evidence presented in support was, first, that trough-faulting was common in adjoining areas and, secondly, that the drillers' log of a boring for water shows unexpected results. The log is detailed in another Memoir (Edmunds, 1928), and is of a boring at Townings Place (347.207)[1] (p. 214).

It cannot be urged too strongly that the use of evidence from drillers' logs, unsupported by detailed local geological mapping, is full of serious pitfalls. The truth of this is apparent when the record of another well at Townings Place, drilled seventeen years later, is compared with the one used in support of trough-faulting by Osborne White (1924). Although these are situated within 300 ft. of each other and on approximately the same geological horizon, the differences in the records are too considerable to give any obvious correlation. The earlier well shows, below a depth of 85 ft., a disproportionate amount of 'rock'. This, variously described as 'slatey', 'chalky' or 'hard', was assumed to be 'sandstone' and, therefore, of Tunbridge Wells Sand age, but it is not necessary that it should be. Local geological mapping has brought out the fact that the lowest group of the Weald Clay (Reeves, 1948, p. 240) is composed of clays, shales and mudstones. These latter are often so hard, when they are freshly exposed, that the full force of hydraulic drills is needed to break them, yet, within a few days of exposure to the atmosphere, they disintegrate into a muddy clay. So mudstones, hard enough to be labelled by the popular term 'rock' in a boring, may easily outcrop as 'clay'. This fact will help in correlation between well and well, and between well and surface exposures, and, further, it will mean that drillers' descriptions may vary with differing methods of drilling. Assuming that the 'rock' logged in the earlier well is mudstone and shale, correlation between it and the later well, and between it and the surface, become easier. There is still too much 'sandrock' shown in the log in comparison with the splendid section which can be so easily measured in the deeply-incised lane between the two wells, but here again, local knowledge can help. The Wivelsfield Sand, mainly consolidated by pressure and never more than loosely cemented, could easily 'cave' and so give a misleading impression of the rocks penetrated. Taking all these possibilities into consideration, the earlier well can fit into the picture given by the excellent agreement between the later well and the measured section. It is, therefore, normal and not abnormal in sequence and not final evidence of trough-faulting. Further, detailed 6 in. to the mile mapping, agreeing with that of the 1 in. to the mile of F. Drew and W. Topley, has failed to bring out any evidence for trough-faulting immediately to the north of the Wivelsfield Sand.

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[1] This and other references are in terms of the National Grid now used on the Ordnance Survey Maps and shown in Fig. 1.

The possibility of faulting to the south of the Wivelsfield Sand was also suggested by Osborne White and on the evidence of the log of a well drilled at Leylands Farm (316.201) (Edmunds, 1928, p. 67). This well reached a depth of 376 ft., and its log shows a very high proportion of 'clay'. On normal dips of the neighbourhood, both the Wivelsfield Sand and the Upper Tunbridge Wells Sand would be expected to occur within this depth, and so a higher proportion of 'sand' ought to be logged, if the sequence in the well is a normal one. However, 'sand with hard clay' is noted between 140 and 150 ft. deep, and this could be correlated with the Wivelsfield Sand especially as local dips are approximately 4° S. If this 'sand and hard clay' is the Wivelsfield Sand, then more 'sand'—the Upper Tunbridge Wells Sand—should occur about 260 ft. deep. Unfortunately, at this crucial part of the well, the drillers, who have previously recorded changes of as little as 3 in., combine together 50 ft. of strata under the description of 'hard clay and sand'. Again local mapping has brought out the fact that this *could be* Upper Tunbridge Wells Sand, for that outcropping in the vicinity is of very fine grain. Mechanical analyses of samples from Breens Farm (373.200), using Boswell's (1918) classification, show:

Fine sand (FS)	14%
Silt and clay (sc)	86%

Such very fine sandstones, almost siltstones, churned up by drilling in a wet hole, might easily appear to the drillers as 'hard clay and sand'. Taking these possibilities into account, it is likely that the well has the normally expected sequence of:

Weald Clay, Group II	140 ft. plus
Wivelsfield Sand	10 ft.
Weald Clay, Group I	110 ft.
Upper Tunbridge Wells Sand	50 ft. plus

A well at 'The Botches' (354.201) (Edmunds, 1928, p. 214) shows a normal sequence.

Once again 6 in. to the mile mapping shows no suggestion of faulting immediately to the south of the Wivelsfield Sand.

(b) **Folding.** No evidence was found, nor has it been suggested in earlier literature, that the Wivelsfield Sand had been brought to the surface by anticlinal folding.

(c) **Dip-faulting.** The sequence and thickness of the Wivelsfield Sand at Townings Place is:

Fine grained sandstone	6 ft.
,, ,, sand	7 ft.
,, ,, sandstone	2 ft.
,, ,, sand	11 ft.
,, ,, sandstone	2 ft.

This is by no means constant throughout the whole area. To the west of the road (B.2036), it is too thin to form any feature, but it thickens rapidly within a quarter of a mile to the east to allow the formation of two small ones, the lower one—and incidentally there are similar ones north of Antye Farm (327.206) and west of Hole Farm (357.208)—being a flat-topped hillock. Near Lunces Hall (333.207) the Sand forms a scarp which is clearly the most important feature of the countryside, but half a mile to the east, where the outcrop crosses the road (B.2112), the scarp is greatly reduced in size and the sandstone probably thinner. It thickens again to form an important scarp north of Townings Place. Anyone who has seen the fluviatile or coastal sandstones of the Upper Fars of South West Persia, is struck by the similarity between these and the Wivelsfield Sand, howbeit on a greatly reduced scale. In the Upper Fars the sandstones, a few inches thick, may easily thicken up over a few hundred yards, to form bluffs of 10–15 ft. in height, and then thin out just as rapidly while another sandstone, deposited a foot or so above, will assume the same form. It is not possible, in any area covered with vegetation, to trace such developments in a detailed way, but it is believed that the sand itself, with two or more consolidated bands within it, may act in a similar way to the Upper Fars Sandstone and form similar, though much smaller, bluffs at slightly varying geological horizons.[1]

For the general argument, however, it will suffice to state that the Wivelsfield Sand in its development from Woodfield Lodge (309.213) to Wivelsfield Hall (353.208) forms a scarp dip-slope feature, the dip varying from 3–4° and the scarp from 5–6°. The first clue in the solution of the problem is that this feature, which is traceable for some 2¾ miles, is lost just east of Wivelsfield Hall.

The second clue is noted some 550 ft. S.29° W. of Hole Farm (357.208), where the junction line mapped between the Wivelsfield Sand and the underlying clay ends abruptly against an exposure of well-bedded sandstone dipping at 3° N.81° E. Mechanical analyses of this sand and the Wivelsfield Sand from Townings Place contrast as follows:

	TOWNINGS PLACE	HOLE FARM
FS	64%	94%
SC	36%	6%

The third clue rests again on a change of direction of a prevailing feature, and the cessation of a fairly readily mappable horizon—that between the Weald Clay and the underlying Tunbridge Wells Sand, just to the north of Ham Wood (356.214). Also, for some distance between the point of the second and the third clues, it is possible to trace a sand (upper)–clay (lower) junction along the north–south ridge. This is the reverse of the normal

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[1] This may apply to other Weald Clay Sandstones.

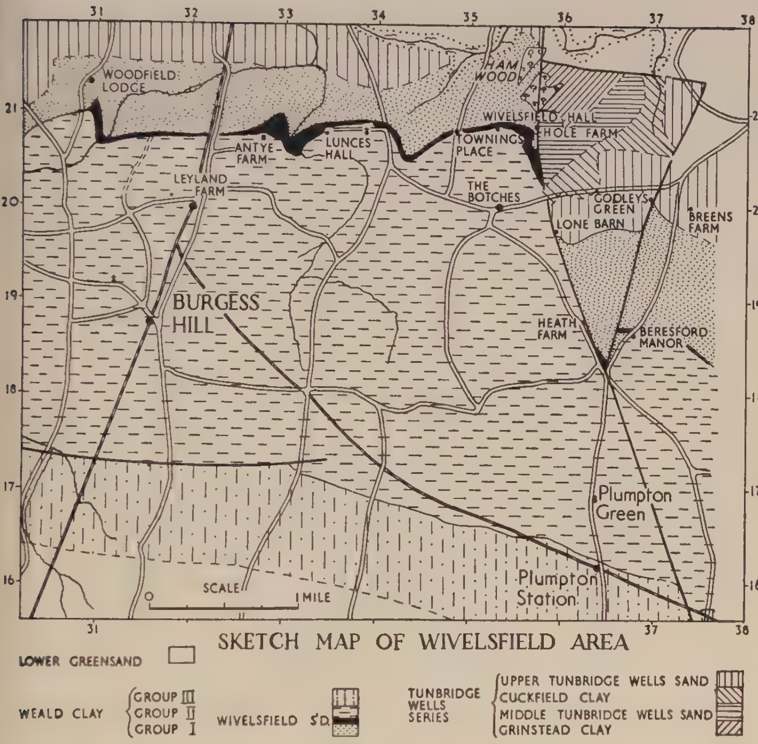

Fig. 1. Map showing distribution of the Wivelsfield Sand

Weald Clay–Tunbridge Wells boundary and adds to the abnormality of the immediate area.

It is to the south-east, and at Godley's Green and Lone Barn (358.199), that the next evidence is seen. Near both these places the junction between the Weald Clay and the Tunbridge Wells Sand 'V's to the north, into the valley, and *away from* the overlying formation. However, at a valley, the outcrop of the underlying formation 'V's *towards* the overlying formation, so here again there is abnormality. Lone Barn lies on the continuation of the suspected fault-line given by clues, one, two and three. Taken together these clues suggest that there is a dip-fault here of considerable dimensions, for there is a horizontal displacement of the top of the Tunbridge Wells Series of 5500 ft. to the south.

If this is true, it should follow that there is a similar displacement in the Wivelsfield Sand. There is a sandstone exposure of an isolated nature capping a small hill 800 ft. S.30° E. of Heath Farm (363.187). This lies

4800 ft. to the south of the last recorded outcrop of the Wivelsfield Sand, a figure which compares favourably with the 5500 ft. given in the paragraph above.

Finally, there is a similar displacement in the Red Clay, which is very readily mappable in the neighbourhood of Plumpton Station (364.162). This displacement has been reduced here to some 1000 ft.

To the east of this dip-fault (although around the 150 ft. contour-line there is much obscuring drift) it is possible to map four alternating sand and clay formations. It is believed that these are representatives of the Tunbridge Wells Series and can be differentiated as follows:

Upper Tunbridge Wells Sand	90 ft.
Cuckfield Clay	15 ft.
Middle Tunbridge Wells Sand	95 ft.
Grinstead Clay	15 ft. plus.

In an area so disturbed, these thicknesses must be regarded as approximate only, but they do compare, not unfavourably, with those recorded between Cuckfield and Haywards Heath (Reeves, 1948).

In the north, the Grinstead Clay and the Middle Tunbridge Wells Sand end abruptly against a line which is marked by the presence of strong chalybeate springs. This line is believed to be a strike-fault. In the east, the swing of the Weald Clay–Tunbridge Wells Sand boundary away from the Weald Clay outcrop at Godleys Green has already been mentioned (p. 273), while, north of this area, the Cuckfield Clay outcrop is seen to aim directly at the great mass of sand which forms North Common. Here again the presence of a dip-fault is recorded, and evidence of its existence strengthened by the isolation of the sand near Heath Farm, and the displacement of it, back again to the north, near Beresford Farm (367.186).

From a structural point of view, then, the results of which are recorded in the sketch map accompanying the paper, it is suggested that the Wivelsfield Clay does not, to quote Topley (1875), 'join the great mass of the Tunbridge Wells Series' but is faulted against them, and that the faulting is of dip-fault type. This would suggest that the Wivelsfield Sand is of Weald Clay age, a fact which fits into the picture of the subdivision of the Weald Clay into lithological Groups (Reeves, 1948), especially as the datum line between Groups II and I is a sandstone. The comparison between this area and that of Henfield–Horsham is therefore as follows:

	HENFIELD–HORSHAM	WIVELSFIELD–PLUMPTON
Group III	350 ft.	260 ft.
Red Clay		
Group II	820 ft.	610 ft.
Sandstone		Wivelsfield sand
Group I	140 ft.	140 ft.[1]

[1] Including 28 ft. of the Wivelsfield Sand.

On stratigraphical grounds, as well as on structual therefore, the Wivelsfield Sand appears to be of Weald Clay age.

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OSTRACODA FROM THE LONDON CLAY

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ABSTRACT.—The present paper consists of systematic descriptions of Ostracoda from the London Clay. One new genus and three new species are recorded. The stratigraphical significance of the Ostracoda is assessed.

1. INTRODUCTION

THERE has been no extensive survey of the Ostracoda from the London Clay since the researches of T. Rupert Jones and C. D. Sherborn in the latter part of the nineteenth century. Unfortunately, these authors, in common with most of their contemporaries, emphasised features which are no longer regarded as of maximum significance in classification. During an examination of the microfauna of the London Clay, carried out at University College, London, by the author during the period 1950 to 1952, numerous well-preserved Ostracoda were identified. A new genus, three new species and ten previously known species were recorded from localities in the London and Hampshire Basins. The standard techniques were used in separation of the fauna. Most of the ostracod-bearing samples were obtained from bores drilled by the Metropolitan Water Board during 1948 and 1949 in connection with the Enborne Valley Reservoir project and kindly lent by Professor H. L. Hawkins, to whom the author is much indebted. The specimens have been presented to the Trustees of the British Museum (Natural History) and registered in their collections. Registration numbers are given with the description of each species in this paper, type and figured specimens bearing separate numbers.

2. SYSTEMATIC DESCRIPTIONS

The class Ostracoda can be divided into a number of orders, of which only two are represented in the present assemblage, namely the Platycopa and the Podocopa, both founded by Sars.

Order: *PLATYCOPA*

Family: CYTHERELLIDAE

Genus: **CYTHERELLA** Jones, 1849

Cytherella compressa (Münster)

1830. *Cythere compressa* Münster, *Jahrb. f. Min.*, etc., p. 64.
1856. *Cytherella compressa* (Münster), Jones, *Monogr. Tert. Ent.*, p. 54, pl. 5, figs. 21, 23.
1856. *Cytherella londinensis* Jones, *Monogr. Tert. Ent.*, p. 55, pl. 5, figs. 20, 22.

Material. In. 46236–39.

Description. The carapace is subovate in side view with the dorsal and ventral margins parallel and slightly convex. The anterior end is evenly rounded, the posterior end obliquely rounded. The maximum width of the carapace is just posterior to the middle. The right valve overlaps the left along the entire periphery and both are smooth. There is no marginal area and the centrally placed muscle-scar area is oval and elevated in both valves. The hinge-structure is adont and comprises a simple groove along the dorsal margin of the larger right valve, into which fits a smooth ridge of the left valve.

Remarks. This species resembles *Cytherella cubensis* Van den Bold (1946), but it lacks the vertical median sulcus found in both valves of the latter. Marked sexual dimorphism occurs in the present species, the male being smaller and relatively more elongate than the female. According to Jones (1856), this species is still extant. Fifteen specimens were studied.

Distribution. Specimens were obtained from four Enborne bores at the stated depths.

Bore 21:	75 ft. 6 in.	Grey sandy clay.
Bore 28:	29 ft.	Stiff grey clay.
	32 ft. 6 in.	Stiff grey clay.
	46 ft. 6 in.	Stiff grey clay.
Bore 36:	24 ft. 6 in.	Stiff dark grey clay.
	30 ft.	Stiff dark grey clay.
	40 ft.	Stiff dark grey clay.
Bore 39:	131 ft.	Stiff grey clay.

Specimens were also obtained from the Upper London Clay at Whitecliff Bay, Isle of Wight. (In. 46286.)

Order: *PODOCOPA*

Family: BAIRDIIDAE

Genus: **BYTHOCYPRIS** Brady, 1880

Bythocypris subreniformis Jones & Sherborn

1887. *Bythocypris subreniformis* Jones & Sherborn, *Geol. Mag.*, **4**, p. 387.

Material. In. 46240.

Description. The carapace is elongate, sub-reniform in shape and laterally compressed with convex dorsal margin lacking cardinal angles. The ventral margin is slightly concave. The left valve slightly overlaps the right dorsally and ventrally and both valves are smooth. The line of concrescence and inner margin diverge anteriorly and the muscle-scar area is circular with several scars. The hinge structure is simple and adont.

Remarks. There is some resemblance between this species and *Bythocypris obtusata* (Sars) (1865), but the latter is sub-quadrate in side view. The valves are extremely fragile in this species and well-preserved specimens are rare in consequence. Four specimens were studied.

Distribution. Specimens were obtained from one Enborne bore. The depth is stated.

Bore 36: 40 ft. Stiff dark grey clay.

Family: CYTHERIDAE

Subfamily: CYTHERIDEINAE

Genus: **CYTHERIDEA** Bosquet, 1852

Subgenus: CYTHERIDEA Stephenson, 1936

Van den Bold (1946) gives the range of this subgenus as confined to the Oligocene (Europe), but it occurs in the London Clay and persists into recent seas.

Cytheridea (Cytheridea) mülleri (Münster)

Fig. A, 2 a, b, c.

1830. *Cythere mülleri* Münster, *Jahrb. f. Min.*, etc., p. 62.
1854. *Cytheridea mülleri* (Münster), Jones, *Quart. Journ. Geol. Soc. Lond.*, **10,** p. 160, pl. 3, fig. 7.
1936. *Cytheridea* (*Cytheridea*) *mülleri* (Münster), Stephenson, *Journ. Paleont.*, **10,** p. 699, pl. 94, figs. 1, 2, 7.

Material. In. 46241–50.

Description. The carapace is tumid, thickest about the middle and elongate, subovate in side view with the greatest height anterior to the middle. The left valve is larger than the right and overlaps the latter. The dorsal margin is arched and angular at the denticular areas; the ventral margin is nearly straight, slightly incurved and flanged centrally. The anterior ends are evenly rounded in both valves and bear five to eight short spines in each valve, those of the right valve being more prominent. The posterior ends of the valves are obliquely truncated and spines may occur in the right valve. The valves are coarsely punctate externally. The valve interiors are smooth with the inner margin and line of concrescence coincident except anteriorly. The marginal area is broad, often reaching a maximum width of 0.08 mm. anteriorly. The radial pore-canals are numerous and the muscle-scar area comprises several centrally placed scars arranged in an oblique row. The hinge-structure is taxodont and consists in the left valve of an elongate, elliptical, anterior socket incised by several transverse grooves and with overhanging dorsal edge, a high, finely crenulate bar, a diamond-shaped depression, another (longer and narrower) crenulate bar and a posterior elongate-oval socket incised by several transverse grooves. The right valve comprises complementary structures.

Remarks. According to Stadnichenko (1927), this species occurs in shallow marine conditions at the present time. It was recorded from Smyrna, the Levant, the Zuyder Zee and Australia by Brady (1878). As a fossil it has a widespread occurrence, being recorded from the Eocene of Texas, Mexico, France, England, Holland, Germany and Australia, the Oligocene of Switzerland, the Miocene of France and Holland and the Pliocene of Holland. Forty-one specimens were studied. Dimensions of figured specimens:

Left valve:	Length	0.72 mm.
	Maximum height	0.38 mm.
Right valve:	Length	0.7 mm.
	Maximum height	0.36 mm.

Distribution. Specimens were obtained from nine Enborne bores at the stated depths.

Bore 21:	75 ft. 6 in.	Grey sandy clay.
Bore 22:	81 ft. 3 in.	Dark grey clay.
Bore 28:	37 ft. 5 in.	Stiff grey clay.
	56 ft. 9 in.	Grey clay.
Bore 32:	32 ft.	Grey clay.
Bore 33:	30 ft.	Grey shelly clay.
	38 ft. 6 in.	Grey silty clay.
Bore 34:	32 ft. 9 in.	Grey clay.
	35 ft. 6 in.	Grey clay.
Bore 36:	21 ft. 6 in.	Stiff dark grey clay.
Bore 37:	51 ft.	Dark grey pebbly clay.
Bore 38:	110 ft.	Stiff grey clay.
	130 ft.	Stiff grey clay.

Cytheridea (Cytheridea) perforata (Roemer)

Fig. A, Fig. 4 a, b, c.

1838. *Cytherina perforata* Roemer, *Neues Jahrb. f. Min.*, etc., p. 516, pl. 6, fig. 11.
1856. *Cytheridea perforata* (Roemer), Jones, *Monogr. Tert. Ent.*, p. 44, pl. 4, fig. 14.

Material. In. 46251–55.

Description. The carapace is tumid and thickest centrally with subovate side view and greatest height anterior to the middle. The left valve is larger than the right and both have arched dorsal margins with the denticulate areas angular and the anterior are especially prominent, being marked by a slight external boss in some specimens. The ventral margins are slightly convex, centrally incurved and flanged. The anterior ends are evenly rounded and smooth; the posterior ends are smooth and tend to be obliquely truncated. The surfaces of the valves are coarsely punctate. Internally, the inner margin coincides with the line of concrescence except anteriorly and the marginal area is very broad, reaching a maximum width of 0.1 mm. anteriorly. The radial pore-canals are numerous and are sometimes grouped into separate clusters. The muscle-scar area is usually obscure, but appears to comprise a set of centrally placed, obliquely arranged scars. The hinge-structure is taxodont and is essentially similar to that of *Cytheridea* (*Cytheridea*) *mülleri* (Münster) described above.

Remarks. This species has been recorded from the Sables Moyens and Calcaire Grossier of France. Seven specimens were studied. Dimensions of figured specimens:

Left valve:	Length	0.89 mm.
	Maximum height	0.53 mm.
Right valve:	Length	0.87 mm.
	Maximum height	0.52 mm.

Distribution. Specimens were obtained from four Enborne bores at the stated depths.

Bore 1:	151 ft.	Grey silty clay.
Bore 28:	37 ft. 5 in.	Stiff grey clay.
Bore 32:	32 ft.	Grey clay.
Bore 38:	145 ft.	Greenish silty clay.

Specimens were also obtained from the Upper London Clay at Whitecliff Bay, Isle of Wight. (In. 46287.)

Cytheridea (Cytheridea) sp.

Material. In. 46256.

Remarks. This species, only represented by a few single valves, possesses the characters typical of the subgenus and is differentiated from the other recorded species of this subgenus by its much greater degree of elongation. Insufficient specimens were found to justify the erection of a new species.

Distribution. The few valves were present in the Enborne bore noted at the stated depth.

Bore 36: 21 ft. 6 in. Stiff dark grey clay.

Subfamily: LOXOCONCHINAE

Genus: **Cytheropteron** Sars, 1865

Subgenus: CYTHEROPTERON Alexander, 1933

This subgenus is characterised by the presence of valvular expansions or alae near the ventral margins.

Cytheropteron (Cytheropteron) brimptoni sp. nov.

Fig. A, 7 a, b, c.

Material. Holotype, In. 46257; other specimens, In. 46258.

Diagnosis. The carapace is subovate in side view with convex dorsal and ventral margins. The posterior end is produced to form a short, blunt, narrow, compressed caudal process. Near the ventral margins of the valves arise prominent alae which are directed posteriorly. The valves are smooth except for a variable number of slight ridges which occur at the dorsal and ventral margins and run parallel to those margins. These ridges disappear anteriorly and on the caudal process a similar but distinct set of ridges occur. Internally, the inner margin and line of concrescence coincide except at the anterior end and the radial pore-canals are relatively few and widely spaced. The hinge-structure is taxodont and consists in the right valve of narrow crenulate ridges placed anterior and posterior to a dorsal, shallow carved ridge and in the left valve of complementary features.

Remarks. This species is similar to *Cytheropteron* (*Cytheropteron*) *nipeensis* Van den Bold (1946), but can be distinguished by the dorsal and ventral ridges, more posteriorly placed alae, broader posterior end and smaller size. Two specimens were studied. This species was named after a town in the Enborne Valley. Dimensions of holotype (figured):

Length	0.3 mm.
Maximum width across alae	0.25 mm.
Maximum height	0.16 mm.

Distribution. Both the holotype and the single other specimen were obtained from the Enborne bore noted and at the stated depth.

Bore 34: 32 ft. 9 in. Grey clay.

Subgenus: EOCYTHEROPTERON Alexander, 1933

This subgenus differs from the previous subgenus in lacking alae and in having a tumid carapace and a hinge-structure which, although still taxodont, has distinctive features. The hinge-bar is denticulate in both valves, the teeth of one valve fitting the sockets between the teeth of the other.

Cytheropteron (Eocytheropteron) sherborni sp. nov.

Fig. A, 5 a, b.

Material. Holotype, In. 46259; other specimens, In. 46260–62.

Diagnosis. The carapace is tumid with the left valve slightly larger than the right, ovate in side view with maximum height centrally. The dorsal margin is arched with distinct cardinal areas and the ventral margin is almost straight with an incurved flange just anterior to the middle. The anterior end is broadly and evenly rounded and the posterior end is truncated with slight caudal processes placed dorsally. The external surfaces of the valves are punctate and ornamented by ridges, the latter running parallel to the periphery and present only on the ventral sides. On the internal surfaces, the marginal areas are broad with fairly numerous, straight, narrow, simple, radial pore-canals. The muscle-scar area is not always clear, but appears to comprise one or several scars arranged in an almost vertical series. The hinge-structure is taxodont and consists in the right valve of two terminal, elongate dental areas divided into several cusps by transverse grooves and between them along the dorsal margin, a uniformly projecting line of small, equidimensional serrations. Complementary features occur in the left valve.

Remarks. Six specimens were studied. This species was named in honour of the late Dr. C. D. Sherborn. Dimensions of holotype (figured):

Length	0.82 mm.
Maximum height	0.49 mm.
Maximum breadth	0.48 mm.

Distribution. Specimens were obtained from two Enborne bores at the stated depths.

Bore 34: 32 ft. 9 in. Grey clay. Holotype obtained here.
Bore 41: 104 ft. 10 in. Grey silty clay.

Family: TRACHYLEBERIDAE

Genus: **HEMICYTHERE** Sars, 1925

Early authors usually assigned species of this genus to *Cythere* O. F. Müller (1785), and Sars (1925) regarded his genus as occupying an intermediate position between *Cythere* and *Cythereis* Jones (1849). The confusion with *Cythere* resulted from the lack of atttention paid to the internal characters of the valves. *Cythere* is a taxodont form in which the inner margin and line of concrescence do not coincide and it comprises 'probably fewer than ten species, recent and fossil', according to Blake (1931). *Hemicythere* has a heterodont hinge-structure and the line of concrescence and inner margin are coincident except anteriorly. Stephenson (1946) stated that *Hemicythere* can only be separated from *Cythereis* by the shape of the carapace, but Triebel (1940) demonstrated that the teeth of *Cythereis* are denticulate. This fact, in addition to the smaller size of the latter, serves to differentiate the two genera.

Hemicythere plicata (Münster)

1830. *Cythere plicata* Münster, *Jahrb. f. Min.*, etc., p. 63.
1889. ,, ,, ,, ; Jones & Sherborn, *Suppl. Monogr. Tert. Ent.*, p. 29, pl. 1, fig. 18.

Material. In. 46263.

Description. The carapace is elongate and subovate in side view with convex dorsal margin and almost straight and sub-parallel ventral margin.

The anterior end is broadly and evenly rounded and the posterior end is truncated. The valve surfaces are smooth except for three longitudinal ridges. The dorsal ridge is slight and placed posteriorly, the median ridge is more prominent and, although posterior, extends more anteriorly and the ventral ridge is the most prominent and extends most of the length of the carapace.

Remarks. One specimen was studied.

Distribution. The specimen was obtained from an Enborne bore at the stated depth.

Bore 31: 17 ft. 6 in. Stiff grey clay.

Hemicythere scrobiculoplicata (Jones)

Fig. A, 3 a, b, c.

1856. *Cythere scrobiculoplicata* Jones, *Monogr. Tert. Ent.*, p. 33, pl. 6, figs. 4, 6.
1889. „ „ „ ; Jones & Sherborn, *Suppl. Monogr. Tert. Ent.*, p. 30.

Material. In. 46264–69.

Description. The carapace is elongate and subovate in side view, with straight dorsal margin and ventral margin slightly incurved centrally and sub-parallel to the dorsal. The greatest height is at the anterior cardinal angle and the anterior end is smooth and evenly rounded. The posterior end is rounded. One or more longitudinal ridges may occur on the valves and, if several are present, the median one is the most prominent. There is a well-marked ornamentation of coarse, reticulately arranged, sub-quadrangular pits which are concentrically placed peripherally. Dorsally viewed, the carapace is elliptical. Internally, there is a broad marginal area with numerous evenly spaced radial pore-canals. The line of concrescence and inner margin coincide except anteriorly. The muscle-scar is simple, ovate and placed in a median position just anterior to the middle. The hinge-structure is heterodont and consists, in the right valve, of an elliptical anterior tooth, broad sub-triangular post-jacent socket, groove and elongate, ovate, outwardly directed posterior tooth. Complementary features occur in the left valve.

Remarks. This species resembles *Hemicythere limbata* (Bosquet) (1852), but the latter has the posterior end angled below the middle and less prominent ornamentation. Twenty-two specimens were studied. Dimensions of figured specimens:

Left valve:	Length	0.7 mm.
	Maximum height	0.41 mm.
Right valve:	Length	0.74 mm.
	Maximum height	0.37 mm.

Distribution. Specimens were obtained from five Enborne bores at the stated depths.

Bore 1: 151 ft. Grey silty clay.
Bore 22: 61 ft. Stiff grey clay.
Bore 28: 29 ft. 2 in. Stiff grey clay.
37 ft. 5 in. Stiff grey clay.
46 ft. 8 in. Stiff grey clay.
56 ft. 9 in. Grey clay.
Bore 31: 7 ft. 8 in. Brown clay.
Bore 38: 60 ft. Grey clayey silt.
90 ft. Stiff grey silty clay.
95 ft. Stiff grey silty clay.

Hemicythere striatopunctata (Roemer)

Fig. A, 1 a, b, c.

1838. *Cytherina striatopunctata* Roemer, *Neues Jahrb. f. Min.*, etc., p. 515, pl. 6, fig. 2.

1856. *Cythere striatopunctata* (Roemer), Jones, *Monogr. Tert. Ent.*, p. 27, pl. 5, figs. 6, 7, 10.

Material. In. 46270–74.

Description. The carapace is sub-quadrangular in side view and elongate with straight dorsal and slightly incurved ventral margins. These margins are almost parallel. The greatest height is just behind the anterior cardinal angle and the anterior end is smooth and evenly rounded. The posterior end is angled centrally, concave above and convex ventrally. Posterior spines may be present ventrally. The valve surfaces are ornamented by a coarse reticulate meshwork. The maximum width of the carapace is slightly anterior to the centre and the carapace is inflated. Internally, there is a broad marginal area with evenly spaced radial pore-canals. The line of concrescence and the inner margin coincide except anteriorly. The muscle-scar lies just below the centre line and slightly anterior to the middle of the carapace. It consists of two depressions placed obliquely, the smaller dorsal one being anterior to the larger ventral one. Both are oval in shape. The hinge-structure is heterodont and consists, in the right valve, of an elliptical anterior tooth, large and deep, subtriangular post-jacent socket, groove and elongate, narrow, outwardly directed posterior tooth. Complementary features occur in the left valve.

Remarks. Fifty-five specimens were studied. Dimensions of figured specimens:

Left valve: Length 0.96 mm.
Maximum height 0.47 mm.
Right valve: Length 0.95 mm.
Maximum height 0.45 mm.

Distribution. Specimens were recorded from four Enborne bores at the stated depths.

Bore 28: 29 ft. 2 in. Stiff grey clay.
56 ft. 9 in. Grey clay.

Bore 34:	32 ft. 9 in.	Grey clay.
	35 ft. 6 in.	Grey clay.
Bore 38:	70 ft.	Grey silty clay.
	120 ft.	Stiff grey clay.
	135 ft.	Grey clay.
Bore 52:	78 ft.	Pebbly clay.

Subfamily: TRACHYLEBERINAE

Genus: **TRACHYLEBERIDEA** gen. nov.

Type species: *Cythereis prestwichiana* Jones & Sherborn.

The carapace is sub-quadrangular in side view and almost quadrate in section, broadening posteriorly in dorsal view, with the anterior end higher than the posterior in side view, the maximum height being reached at the anterior cardinal angle. The hinge margin is straight and sub-parallel to the ventral margin, which is incurved centrally. The left valve is slightly larger than the right, most conspicuously overlapping at the antero-dorsal angle. The anterior end of the carapace is rounded and denticulate ventrally with prominent rim, while the posterior end is compressed and sub-triangular in side view with ventral spines and occasionally a marginal rim. The ornamentation comprises a fine, reticulate meshwork. No tubercles are developed, except the sub-central one which may have a ridge posterior to it. Internally, the line of concrescence and inner margin coincide, the selvage is prominent and the muscle-scar area lies in a deep depression and consists of two parts, a group of four posterior scars and a group of two (separate) anterior scars. The radial pore-canals are very numerous and sometimes thickened centrally. The hinge-structure of the right valve comprises a conical anterior tooth with a deep, small postjacent socket and an elongate, narrow posterior tooth which is serrate and divided into four to six lobes. The hinge margin between the postjacent socket and the posterior tooth bears a narrow bar above it formed by the dorsal edge of the valve; below this bar is a narrow groove. The hinge-structure of the left valve comprises a circular, deep, anterior socket, a well-developed postjacent conical tooth and another oval socket at the posterior end. Between these terminal elements of the hinge line, there is a narrow bar.

Sylvester-Bradley (1948) noted that 'in the upper Cretaceous, it [i.e. *Cythereis s.s.*] is accompanied by forms transitional to *Trachyleberis*. Possibly another generic name should be applied to forms with an entire anterior hinge element, but denticulate posterior.' Such transitional forms should be included within the present genus, the type species of which occurs in the London Clay.

The genus differs from the other intermediate form *Bradleya* Hornibrook (1952) in lacking any tubercles other than the sub-central tubercle in lacking ventro-lateral and dorso-lateral keels, in always possessing ornament (*Bradleya* is sometimes smooth), in muscle-scar arrangement (the four posterior scars interconnect in *Trachyleberidea*, but are separate in *Bradleya*) and in having fewer anterior denticulations on the carapace. Hornibrook (1952) referred to his genus as 'medium sized to large', a further difference from *Trachyleberidea* which is a relatively small genus.

Trachyleberidea prestwichiana (Jones & Sherborn)

Fig. A, 6 a, b, c, d.

1887. *Cythereis prestwichiana* Jones & Sherborn, *Geol. Mag.*, **4**, p. 454, pl. 11, fig. 11.

1934. ,, ,, ,, ,, ,, ; Alexander, *Journ. Paleont.*, **8**, p. 220, pl. 32, figs. 14, 15.

Material. In. 46275–80.

Description. The carapace is sub-quadrangular in side view with quadrate section, broadening posteriorly in dorsal view with the dorsal margin straight and sub-parallel to the ventral margin which is incurved centrally. The left valve is slightly larger than the right and overlaps it conspicuously at the antero-dorsal angle. The rounded anterior end has usually six ventral, blunt spines or denticles and there are three or four placed ventrally at the posterior end, the former being more prominent than the latter. The valve-surfaces are reticulate with rims, sub-central tubercle and a short ridge which runs posteriorly from the tubercle and terminates in a sudden posterior slope ending in the denticulate posterior margin. The internal characters are essentially those previously described in the diagnosis of the genus.

Remarks. The specimens recorded from the Eocene of Texas by Alexander (1934) differ from the present ones in having fine spines projecting into the pits of the reticulations. Ten specimens were studied. Dimensions of figured specimens:

Left valve:	Length	0.64 mm.
	Maximum height	0.36 mm.
Right valve:	Length	0.65 mm.
	Maximum height	0.32 mm.

Distribution. Specimens were recorded from five Enborne bores at the stated depths.

Bore 28:	29 ft. 2 in.	Stiff grey clay.
Bore 34:	40 ft. 4 in.	Dark grey silty clay with shells.
Bore 36:	40 ft.	Stiff dark grey clay.
Bore 38:	110 ft.	Stiff grey clay.
	145 ft.	Greenish silty clay.
Bore 55:	76 ft.	Grey silty clay with lignite.

Genus: **TRACHYLEBERIS** Brady, 1898

This genus was extended by Sylvester-Bradley (1948) to accommodate Tertiary and Recent species hitherto assigned to *Cythereis* Jones (1849).

As Triebel (1940) stated, the latter possesses denticulate anterior and posterior hinge-elements. In all other respects than hinge structure, muscle-scar pattern and ornament, *Trachyleberis* resembles *Trachyleberidea*. In *Trachyleberis*, however, the posterior tooth is not serrate, the muscle-scar is a simple crescent placed anteriorly and there may be tuberculate ornament (distinct from the sub-central tubercle).

Trachyleberis bowerbankiana (Jones)

1856. *Cythereis bowerbankiana* Jones, *Monogr. Tert. Ent.*, p. 38, pl. 6, figs. 7, 8.

Material. In. 46281.

Description. The carapace is elongate and subovate in side view with evenly rounded, ventrally denticulate anterior end and finely denticulate posterior end. The valves are inflated and there is a very strongly developed ventral ridge. The valve-surfaces are sometimes faintly reticulate, but more commonly they are smooth with prominent punctations. The sub-central tubercle is not well-marked. Internally, the valves have relatively few, widely spaced, simple radial pore-canals, prominent selvage and coincident line of concrescence and inner margin. The muscle-scar is obscure in the available specimens. The hinge-structure is heterodont with, in the right valve, a conical anterior tooth, postjacent socket, median groove and posterior conical or elongate tooth. Complementary features occur in the left valve.

Remarks. Four specimens were studied.

Distribution. Specimens were obtained from one Enborne bore at the stated depth.

Bore 31: 17 ft. 6 in. Stiff grey clay.

Trachyleberis enborni sp. nov.

Fig. A, 8 a, b.

Material. Holotype, In. 46282; other specimens, In. 46283.

Diagnosis. The carapace is sub-ovate in side view with bluntly rounded anterior and truncate posterior ends; the former is smooth and higher. There are no distinctly marked cardinal angles. The valves are almost equal in size and, in dorsal view, the carapace is much compressed. There is an irregular reticulate meshwork on the valve surfaces, but it does not cover them completely, being most strongly developed at the anterior ends. Towards the posterior ends, this reticulation becomes divided into dorsal, median and ventral portions which are sub-parallel to the margins. The individual depressions of the ornament are of polygonal shape and those in the region of the sub-central tubercle are the deepest. The anterior and part of the dorsal margins are serrated in side view, the notches being slight and the intermediate parts of the margin rounded. No spines occur on the valve surfaces, but a prominent tubercle is present in the postero-ventral angle of each valve. Internally, the line of concrescence and inner margin coincide and the selvage is well-marked. The muscle-scar area is simple and consists of a single crescentic scar placed just anterior to the middle. The hinge-structure is heterodont. In the right valve there is a conical anterior tooth, a postjacent socket and a simple posterior tooth with a median groove between the postjacent socket and the posterior tooth. Complementary features occur in the left valve.

Remarks. Two specimens were studied. This species was named after the Enborne Valley. Dimensions of holotype (figured):

Length	0.56 mm.
Maximum height	0.33 mm.
Maximum width	0.25 mm.

Distribution. Both the holotype and the other specimen were obtained from one Enborne bore at the stated depth.

Bore 28: 32 ft. 4 in. Stiff grey clay.

Trachyleberis spiniferrima (Jones & Sherborn)

1887. *Cythereis spinossissima* Jones & Sherborn, *Geol. Mag.*, **4**, p. 452, fig. 2.
1889. *Cythereis spiniferrima* Jones & Sherborn, *Suppl. Monogr. Tert. Ent*, p. 34, fig. 3.
1934. ,, ,, ,, ,, ,, ; Alexander, *Journ. Paleont.*, **8**, p. 220, pl. 32, fig. 11.
1936. ,, ,, ,, ,, ,, ; Davis, *Proc. Geol. Assoc.*, **47**, p. 339.

Material. In. 46284–85.

Description. The carapace is elongate and subovate in side view with evenly rounded, denticulate anterior end and sub-triangular posterior end which is also denticulate. There is a well-marked peripheral rim and the dorsal and ventral margins converge posteriorly. The dorsal margin is straight and the ventral margin has an incurved portion just anterior to the middle. The external ornament consists of a series of faintly marked reticulations, which are most prominent towards the periphery, and a set of spines arranged irregularly and independently of the reticulations. The spines tend to be most prominent marginally. Internally, the marginal area is narrow and the muscle-scar simple and anteriorly placed. The radial pore-canals are straight, numerous and regularly spaced. The hinge-structure is heterodont and consists in the right valve of an anterior conical tooth, an elliptical postjacent socket and a narrow, elongate posterior tooth with a median dorsal groove between the postjacent socket and the posterior tooth.

Remarks. This species is cosmopolitan in its occurrence and has been recorded from the Midway (Eocene) of Texas by Alexander (1934), the

Paleocene of the Salt Range (Punjab) by Latham (1938) and the Paleocene of Guatemala by Van den Bold (1946). Four specimens were studied.

Distribution. Specimens were recorded from two Enborne bores at the stated depths.

Bore 28: 32 ft. 4 in. Stiff grey clay.
Bore 31: 7 ft. 8 in. Brown clay.
17 ft. 6 in. Stiff grey clay.

3. STRATIGRAPHICAL SIGNIFICANCE OF THE OSTRACODA

Lack of understanding of the important structural features of the Ostracoda by earlier authors often led to grouping of superficially similar forms under one specific name and hence to the erroneous impression that most species are long-ranged and the subsequent implication that the Class is of little stratigraphical importance. This is untenable in the light of recent knowledge. Stephenson (1937, 1938), Van den Bold (1946), Kingma (1948) and others have shown that some species have a considerable horizontal and restricted vertical range making them useful as stratigraphical indicators. In the London Clay, the Ostracoda are fairly numerous in species, but not in individuals, and in view of the small numbers of specimens, it is not an easy matter to assess the value of the species as possible zonal forms. Analysis of the lithology of the samples from which the species were obtained and comparison with the lithology of the numerous samples which did not yield Ostracoda, showed that clay-beds were much the most favourable environment for the organisms and that only species of *Cytheridea* occur in the sandy and silty beds in appreciable numbers. This is an interesting confirmation of the opinion expressed by Van den Bold (1946) that the Ostracoda are a more adaptable group than the Foraminifera, 'especially species of *Cytheridea*'. Even these latter, however, showed a diminution in numbers in the less suitable sands and silts. They are found in the lower (sandy) part of the London Clay in the Enborne Valley bores and may be considered as characteristic of it. Among other forms, *Hemicythere striatopunctata* (Roemer) and *Hemicythere scrobiculoplicata* (Jones) are relatively numerous and occur primarily in the clay-beds of the lower part of the Middle London Clay of the Enborne Valley. They are capable of tolerating silty environments, however, though in reduced numbers. According to Jones & Sherborn (1889), these species range into Middle and Upper Eocene and Oligocene strata as also do the species of *Cytheridea* recorded in this paper. Although *Trachyleberidea prestwichiana* (Jones & Sherborn), *Trachyleberis bowerbankiana* (Jones) and *Trachyleberis spiniferrima* (Jones & Sherborn) appear to be confined to the London Clay, they are not sufficiently numerous to be zonally useful. Since the numbers of specimens of potentially zonal

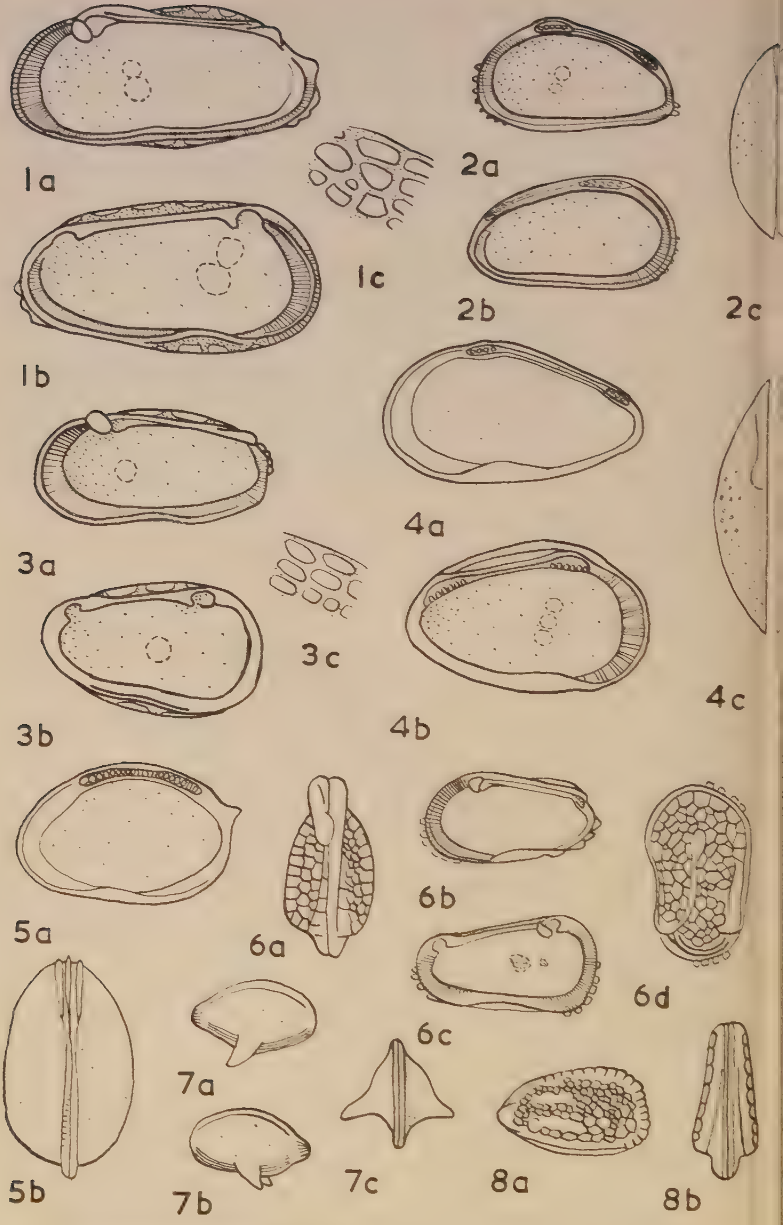

Fig. A. Ostracoda from the London Clay. (See explanation, p. 291) forms are small at any one horizon, the present author considers it impossible to utilise these members of the Ostracodan fauna in zoning the London Clay.

ACKNOWLEDGMENTS

The author wishes to express thanks to Professor H. L. Hawkins who made available the samples from the Enborne Valley, and to Mr. R. Baker for access to the Ostracodan collections at the British Museum (Natural History).

EXPLANATION OF FIGURE A

Approximate magnification × 36, except where otherwise stated.

1. *Hemicythere striatopunctata* (Roemer). In. 46274.
   a. Internal view of right valve.
   b. Internal view of left valve.
   c. Part of external surface showing ornament. × 72.
2. *Cytheridea* (*Cytheridea*) *mülleri* (Münster). In. 46250.
   a. Internal view of right valve.
   b. Internal view of left valve.
   c. Dorsal view of left valve.
3. *Hemicythere scrobiculoplicata* (Jones). In. 46269.
   a. Internal view of right valve.
   b. Internal view of left valve.
   c. Part of external surface showing ornament. × 83.
4. *Cytheridea* (*Cytheridea*) *perforata* (Roemer). In. 46255.
   a. Internal view of right valve.
   b. Internal view of left valve.
   c. Dorsal view of left valve.
5. *Cytheropteron* (*Eocytheropteron*) *sherborni* sp. nov.
   a. Internal view of right valve. In. 46262.
   b. Dorsal view of carapace. Holotype. In. 46259.
6. *Trachyleberidea prestwichiana* (Jones & Sherborn). In. 46280.
   a. Dorsal view of carapace.
   b. Internal view of right valve.
   c. Internal view of left valve.
   d. External view of right valve.
7. *Cytheropteron* (*Cytheropteron*) *brimptoni* sp. nov. In. 46257.
   a. View of carapace from right side. Holotype.
   b. View of carapace from left side. Holotype.
   c. Dorsal view of carapace.
8. *Trachyleberis enborni* sp. nov. In. 46282.
   a. View of carapace from right side. Holotype.
   b. Dorsal view of carapace. Holotype.

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GEOLOGY AND GEOMORPHOLOGY IN SOUTHERN NORDAUSTLANDET (NORTH-EAST LAND), SPITSBERGEN

By H. R. Thompson

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ABSTRACT.—The paper is a detailed analysis of 150 sq. mi. of an Arctic island. Some new data concerning the Carbo-Permian and Triassic rocks are presented and evidence is submitted, which points to the dolerite intrusions being sills. Raised beaches up to 400 ft. above sea level are described and various types of shoreline are differentiated. Comments are made on glacial geomorphology and the ice-margin is shown to have fluctuated in recent years. The glacier-caps in the interior of the island are now all but stagnant.

1. INTRODUCTION

NORDAUSTLANDET (otherwise known as North-East Land) is the second largest island of the Spitsbergen archipelago, having an area of about 6000 sq. mi. It lies north of Scandinavia, on the eightieth parallel, and is largely covered by ice in the form of several glacier-caps. Over long distances the ice fronts directly on the sea, but elsewhere strips of bare land of varying width form the coast. Landing on one such ice-free shoreland, an Oxford University Expedition established its base near Torellneset, the south-west cape of the island, on 20 July 1949 (Fig. 1). While the other members of the party undertook sledge journeys to investigate Bråsvellbreen (Fig. 1), the author spent seven weeks studying

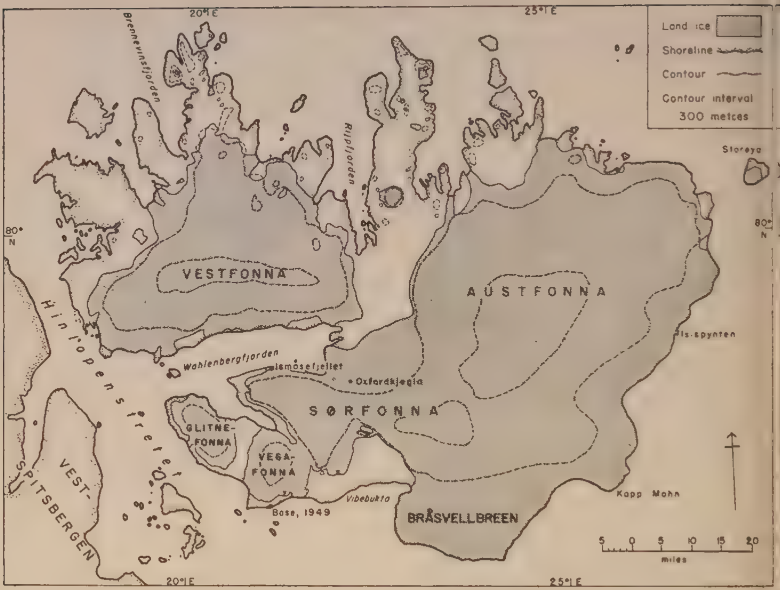

Fig. 1. Nordaustlandet, Spitsbergen, the south coast of which was studied. Based on Glen (1941*b*), by permission of A. R. Glen and the Royal Geographical Society. Amendments from surveys by the Oxford University Expeditions of 1949 and 1951

the geology, landforms and ice-features of the area accessible from the base (Figs. 2 and 3).

Professor Ahlmann's classification of glaciers is used where possible (Ahlmann, 1948, p. 61). The place-names are those approved by the Norsk Polarinstitutt ('The Place Names of Svalbard', *Skrift. Svalbard Ishavet*, No. 80, 1942), except for 'Torellnesfjellene' and 'Balstadfjellene' (Figs. 2 and 3) which are used provisionally.

Note.—Since the latter part of each place-name is written in Norwegian, the following translations may be useful:

breen	the glacier.	kjegla	the cone.
bukta	the bay.	landet	the land.
dalen	the valley.	neset	the cape.
fjellet (–ene)	the hill(s).	øya (–ane)	the island(s).
fjorden	the fjord.	pynten	the point.
fonna	the ice dome.	stretet	the strait.

2. GEOLOGY

Sandford (1926, 1950) divides Nordaustlandet into two roughly equal parts. In the north, granites and gneisses are associated with Pre-Cambrian and Lower Palaeozoic sediments folded in a NNE.–SSW. direction. In the south, the rocks are little disturbed and include Carbo-Permian limestones and Triassic shales, together with dolerite of Cretaceous or early Tertiary age (Orvin, 1940, p. 38). The area to be described lies within the southern region.

(a) **Carbo-Permian rocks.** Only one Carbo-Permian outcrop (some fifteen miles east of the base) was visited (Fig. 2). Grey fossiliferous limestone and chert bands are exposed in a valley 15 ft. deep. They lie flat and display N.–S. and E.–W. joint-systems. Their altitude above sea level (180 ft.) is similar to that of Elton's 'snow and ice' field, four miles to the east (Sandford, 1926, p. 640). The new exposure is the westernmost known on the south coast of Nordaustlandet.

(b) **Triassic rocks.** Trias exposures occur in six places; three in 'Balstadfjellene' and three in 'Torellnesfjellene' (Fig. 2). The former are the farthest east yet found in Nordaustlandet, and, indeed, in Spitsbergen. Their discovery narrows the gap between known Triassic and Carbo-Permian outcrops to 6¼ miles, part of which distance is obscured by ice-lobe Z (Figs. 1–3). The boundary between the two systems probably lies in the depression occupied by the lobe (Fig. 2). (Cf. the geological map of Svalbard in Orvin, 1940, on which the boundary is placed at Rosenthalbreen.)

The outcrops in 'Balstadfjellene' occur on Hill 780 at an altitude of 750 ft. Two lie in runnels and one was found beneath surface débris. All the beds are flat-lying and consist of fossiliferous shale, grey-black and brown in colour. Frost-shattered and morainic 'flakes', similar to the shale *in situ*, occur in large quantities along the summits and flanks of Hills 780 and 1020 and in the valley to the south. Evidently, there is much Triassic rock not only in 'Balstadfjellene' but for an uncertain distance inland.

The first Triassic outcrop in 'Torellnesfjellene' occurs near Hill 540, at an elevation of 450 ft. Black carbonaceous fissile shale, dipping 2–3° SW., is exposed to a depth of five feet in a valley. Shaley 'edgewise conglomerate' is to be seen in all directions, implying a wide extension of the same bedrock. The second outcrop, 300 yds. to the south and at an altitude of 500 ft., stands up as an isolated ridge five feet high. Fossiliferous black fissile shales and mudstones, one horizon of which is calcareous, are exposed. They dip approximately 10° SW. The remaining exposure of the group lies on the western flank of Hill 699, at an altitude of 400 ft. The rock is again fossiliferous black carbonaceous shale, dipping very gently SW. in a series of miniature cuestas. As before, large masses of shale débris, which become more closely packed and more nearly horizontal with depth, surround the outcrop.[1]

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[1] See Postscript, p. 311.

(c) **Dolerite.** The basaltic rock, always (though sometimes incorrectly) known in Spitsbergen as dolerite, is often seen *in situ*. Of the main exposures, Hills 180, 620, 300, 480 and 770, display fine columnar jointing, which, together with the comparative flatness of the summits, makes it seem probable that they are parts of horizontal sheets. That these are probably sills is indicated by the discovery of 'baked' sedimentary rock on top of the dolerite. These sediments, which lie at levels where Triassic shale is to be expected, occur *in situ* at four points in 'Torellnesfjellene'. The upper margin of the dolerite itself was seen to be chilled, both in 'Torellnesfjellene' and in 'Balstadfjellene'.

The dolerite occurs at somewhat inconstant elevations. This may be due to subsequent faulting, to apophyses, to the presence of sills at several levels, or to a combination of factors.

(d) **Loose material.** Moraines, raised beaches and other superficial deposits yield mostly dolerite, shale, limestone and chert fragments. Some of the limestone and chert fragments have been 'baked'. The few granite and gneiss erratics must have been brought to the area either by land-ice or, at periods of higher relative sea level, by floating ice. They possibly originated in northern or eastern Nordaustlandet and have travelled at least twenty-five miles.

3. SHORE FEATURES

The area investigated fronts on the sea for a distance of some twenty miles and includes Torellneset, the south-westernmost point of Nordaustlandet. Three main types of shore are involved (Fig. 3).

(a) **Shoreline sand-ridge.** The first and most extensive type, comprising three-quarters of the total frontage, consists of a ridge of partly unbedded sand and gravel up to fifty yards broad and eight feet high. The ridge is steeper on its seaward than on its landward side and its surface is pitted with tiny kettle-holes. In places it 'ponds back' melt-streams to form lagoons. Its extraordinary continuity is broken only by the narrow gorge-like outlets of melt-streams, by the sand-cliffs and ice-cliffs to be described, and, especially to the east of 'Balstadfjellene', by small deltas of various types.

While the origin of such shoreline ridges has often been discussed, it is probable that all have not been formed in the same way. Craig (1916, p. 285), Sandford (1929, p. 550) and Balchin (1941, p. 285) have considered them in other parts of Spitsbergen, as have Gilbert (1885, Ch.V) and Leverett & Taylor (1915, p. 337) in the Great Lakes region. Our investigations in Nordaustlandet show that several distinct processes are involved.

The first process, which may well be dominant, is normal wave-action. The shoreline sand-ridge has much the same form as an offshore bar, and both features are flanked by erosional depressions in the sea-bed. The ridge, like the bar, may therefore be mainly the result of submarine abrasion and subaerial deposition. Indeed, it may be that in southern Nordaustlandet there is a youthful shoreline of emergence fringed by water sufficiently deep for the expectable sand-bar to develop, not offshore, but on the edge of the land itself.

A second process, well known around the Great Lakes, results from temperature fluctuations during the winter, causing sheets of 'fast-ice' to expand and contract alternately. Each contraction gives rise to tension-cracks which are promptly filled by new ice. Any subsequent expansion of the ice exerts pressure on the inshore sea-bed and thus enlarges the shoreline sand-ridge. Near Torellneset both bottom-deposits and 'fast-ice' had buckled under this process.

In the third place, since the sea-bottom close inshore near Torellneset is sandy and slopes fairly steeply, the impact of grounding floes—driven ashore by winds—is sudden and effective in rucking up material from below sea level. Glen (1938) has described how even in winter the pack-ice around Nordaustlandet is sometimes broken up and scattered by gales, and the rafting of floes may therefore occur at any season.

The fourth process is the accumulation of débris on stranded ice-floes and on the remnants of winter 'fast-ice'. Such 'ice-cores' in the shoreline sand-ridge were exposed in several places and at varying stages (including the early or dirt-cone stage) of development.

Other contributors to the formation of the ridge are icebergs and the tide. Icebergs from time to time deposit boulders and push up large quantities of detritus from the sea-bottom, while the tide, with a mean range of only three feet, aids the wind in the stranding of floes.

The sand-ridge does not form a straight shore, but rather swings in a series of bays and cusps—a fact which tends to encourage a belief in the dominance of wave-action in the building of the ridge itself (Lewis, 1938). A gentle current sets alongshore, from east to west, and it is from the Carbo-Permian area in the east that much of the sand and gravel of the ridge seems to have come. The débris appears to have drifted in a direction contrary to that of the prevailing north-west wind.

At Torellneset the westward-flowing current meets another moving down Hinlopenstretet. The latter is the stronger, mainly because it is the more constricted, and has forced the small spit of Torellneset to recurve towards the east (Figs. 1 and 3).

(b) **Sand-cliffs.** Between Torellneset and Mariebreen (Fig. 3), though not reaching either, is a line of sand-cliffs about one and a half miles long. The height of the cliffs ranges from 100 ft. in the south to 150 ft. in the north. It is uncertain why, at this one place alone, the gently sloping coastal plain of southern Nordaustlandet should be totally lacking.

Perhaps wave-erosion has been particularly effective at this point. It may be that the lower beaches have been truncated by recent north–south faulting. Again, the high ice-foot of 1949 may have concealed solid rock below the very thick sand and gravel deposits of the cliff-top.

(c) **Ice-cliffs.** The last type of shore comprises the truncated ends of two small glaciers. In Augustabukta, Mariebreen reaches the sea on a front of one mile and displays cliffs up to 80 ft. in height. The cliffs of Rosenthalbreen, in Ulvebukta, attain a maximum elevation of 30 ft. and a width of one and a half miles. In each case the cliffs are highest in the centre, tapering off toward the margins and finally sloping steeply down to the raised beaches on which the glaciers lie. Both lines of cliffs are concave landward in plan and conform exactly to the trend of the adjoining sandy shorelines.

While the very fact that cliffs occur suggests that the ice must be in motion, the seaward thinning of both glaciers and the total absence of crevasses and of morainic material implies that neither is in a particularly active condition. No calving of icebergs was observed, nor was the noise of calving heard. It is unlikely, on topographical grounds, that ice extends far below sea level in either case, and the cliff-form is presumably maintained by piecemeal collapse of the ice under the attack of waves and limited basal melting.

4. RAISED BEACHES AND MELT-STREAMS

(a) **Raised beaches.** Rising inland from the shoreline and largely free of vegetation is the coastal plain, identified by Ahlmann (1933–4) as the strandflat. It is an area of tier upon tier of raised beaches which sweep along the coast in bays and cusps, after the manner of the modern shoreline. The beaches are shingly on the surface, whence wind and melt-water have removed the fine particles, but they become increasingly sandy and silty with depth. Most of the material appears to be derived from Carbo-Permian sediments. Some of this has probably reached its present location by a process of beach-drifting from the east, but much of it, including all that composed of shale and dolerite, may be local wave-worked outwash. The Carbo-Permian materials take the form of limestone and chert pebbles, but the dolerite occurs as cobbles and boulders and the Triassic shale as angular flakes.

Except at the sand-cliffs (discussed earlier) the beaches everywhere rise fairly gently from sea level: even Mariebreen and Rosenthalbreen appear to rest on a complete succession of beaches. The lower levels are smoothly sloping, rather than terraced, though in every case there is a low ridge of lichened cobbles marking the former storm-beach.

Farther back from the shore, the gradient of the strandflat increases and steps, irregular in lateral distribution, become prominent. The steps

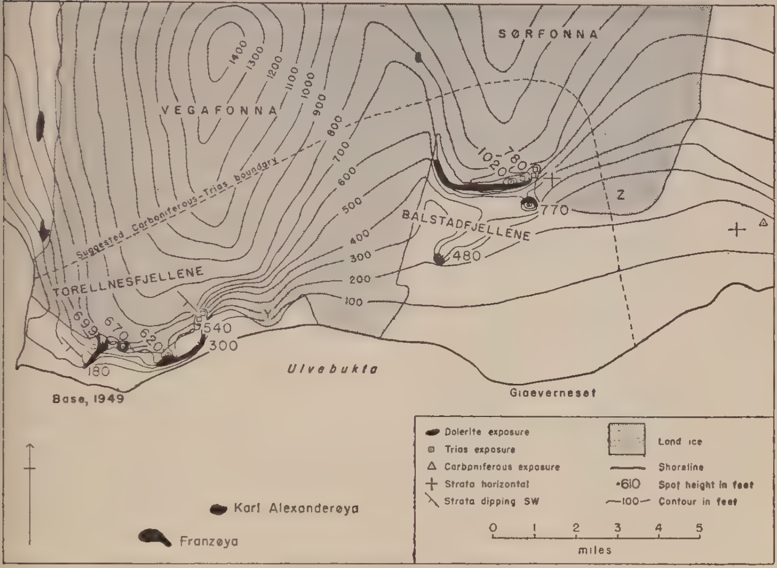


Fig. 2. Geology of south-western Nordaustlandet. Data mainly from surveys by the Oxford University Expeditions of 1949 and 1951: some details from Orvin (1940) and Glen (1941*b*). The place names 'Torellnesfjellene' and 'Balstadfjellene' are provisional only. Some Jurassic is included in the western Triassic exposures

are often marked by snow-banks and by very well rounded, but little weathered, dolerite boulders, some of which are of considerable size. Between the boulders lie white pebbles like those of the flatter beaches. Although most of the steps are probably old sea-cliffs and the majority of the boulders merely débris from these cliffs, no bedrock exposure was ever located at such a step. The boulders themselves are most numerous near the dolerite hills and may have originated in part as scree which was moved downwards by gravity, by ice and by melt-water, and then rounded and reworked into storm-beaches by the waves of higher relative sea levels. Some of the boulder-fields may represent the locations of wave-altered moraines.

The serried ranks of beaches sweep seawards and landwards in conformity with the outlines of the topography. In 'Torellnesfjellene' many of the beaches are 'pinched out' against dolerite cliffs, but farther east the long spur of Giaeverneset is marked by a splendid series of terraces which rise smoothly to 'Balstadfjellene', five miles inland. Beyond ice-lobe Z the beaches attain their maximum width of six miles (Glen, 1937, p. 300). The material of Glen's beaches differs somewhat from that occurring to the west in containing much yellow-weathering shale in addition to the components already mentioned.

The upper altitudinal limit of the raised beaches is difficult to determine with any precision. In some places the ice has re-advanced and in others the terrain is too broken to retain clear terraces. The beaches, to which Glen refers, reach an elevation of at least 400 ft. In 'Balstadfjellene' also, unmistakable beaches were found up to 400 ft., while pebbles similar to those of the beaches were found all the way to the summit of Hill 480. In 'Torellnesfjellene' beaches were identified with certainty to a height of 200 ft., while in several places well-preserved but isolated features, having the characteristics of raised beaches, occurred as high as 350 ft. Most of the water-rounded boulder-fields, already mentioned, lay at altitudes between 250 and 350 ft. Rounded limestone pebbles were found near the summit of Hill 699; but since one is reluctant to postulate beaches at such an altitude, it is perhaps wisest to explain these summit pebbles as outwash material—a conclusion which may lend weight to the previously stated belief that much of the raised beach material itself is no more than outwash reworked by the waves. Well-developed terraces also occur to heights of 200 ft. on Karl Alexanderøya and Franzøya. Both islands seem to have been completely submerged at no distant date.

Although no shells were found in the raised beaches, some very large bones, apparently those of a whale, were found 400 yds. inland and at an elevation of 50 ft., near Torellneset.

The maximum elevations of raised beaches just mentioned—350 to 400 ft.—are comparable with those recorded by other workers in Spitsbergen. Sandford (1926, p. 641) gives a maximum figure of 200 ft. in Wahlenbergfjorden, but records Carslake's estimate of 500 ft. in 'Balstadfjellene' (p. 546). Balchin (1941, *passim*) describes raised beaches up to 300 ft. in Vestspitsbergen, but his beaches are tilted, whereas those in southern Nordaustlandet, perhaps because they run parallel to and not at right-angles to the isobases, are more or less horizontal. Peach (1916, *passim*) states that raised beaches are well developed up to 240 ft. in Vestspitsbergen and mentions less common examples at 260 and 400 ft.

Whether or not Nordaustlandet is still rising relative to sea level is uncertain, though the lack of cliffing at the sea's edge and the gentle and continuous slope of the lower beaches, certainly suggest that elevation still persists.

(b) **Melt-streams.** The raised beaches are in an initial stage of dissection by countless melt-streams. Many of the streams are true consequents on the newly emerged coastal plain, but some, especially those of the large area of bare land north of Vibebukta, are extended consequents from the 'oldland' behind. Few of the streams have tributaries, except in the muddy and confused collecting grounds near the edges of the glacier-caps, where there are dendritic drainage-patterns.

In 1949, summer temperatures were apparently lower than usual and it was very noticeable that the melt-streams were underfits, even in their small valleys. The depth of incision into the raised-beach shingle and sand was usually less than 15 ft., though 'canyons' 40 or 50 ft. deep were observed beside Mariebreen and Rosenthalbreen. The valleys had flat floors, aggraded with gravel—some of it true outwash, the rest derived from the beaches—and steep angular sides. Except for the snow-banks lining each wall, the melt-stream valleys had most of the characteristics of desert wadis—as indeed they should have in view of the prevailing lack of vegetation, small precipitation and irregular regimen.

The streams themselves, in 1949, were very clear and flowed in braided channels among their own gravels. That large-scale transport occurs from time to time is witnessed not only by these same gravels, but by the remarkable series of small deltas and delta-fans in Augustabukta, Ulvebukta and especially Vibebukta. The destructive work of the streams seems to have been mainly concentrated in the unorganised headwater regions previously mentioned. In such areas the raised beach material has been stripped off or dissected into hillocks, exposing large areas of homogeneous scree and mud derived from nearby bedrock.

Apart from the tidal lagoons formed behind the shoreline sand-ridge, there are a few small lakes at various altitudes on the raised beaches. Most of them are elongated, parallel with the beaches, and may themselves have originated as sea-level lagoons. Some may have developed consequently upon watertight depressions in the emergent coastal plain. Again, some of the lakes may possibly occupy kettle-holes. Most of them are in any case independent of the melt-streams.

5. HILLS AND VALLEYS

The unspectacular hills of southern Nordaustlandet comprise two quite distinct groups—'Torellnesfjellene' and 'Balstadfjellene'—ten miles apart. Each group appears to be part of the dissected margin of a subglacial plateau. The observer's impression that the plateau has an east–west slope is confirmed by the surveyor's spot-heights: the main peaks of 'Balstadfjellene' rise to 770–1020 ft., whereas their equivalents in 'Torellnesfjellene' attain only 620–699 ft.

A short distance inland from the hills, the surface of both glacier-caps (Vegafonna and Sørfonna) rises steeply, forming an intermittent 'ice-scarp' which runs from east to west. The setting of this feature and the crevasses along its base leave little doubt but that it conceals a rock-cliff. This cliff is almost certainly the edge of the main interior plateau of Nordaustlandet, which Ahlmann believes to lie at an elevation of 1200–1350 ft. (Ahlmann 1933–4). It therefore appears that 'Balstadfjellene' and 'Torellnesfjellene' have been formed from a partially developed erosion-surface intermediat between the strandflat and the main plateau. The intermediate surface is however, well above that identified by Ahlmann (1933–4) as the 'lowlan area'.

All the hills are composed mainly of dolerite and all are bounded by the steep slopes or scarps which are to be expected in a dissected plateau o hard rock. The slopes are commonly mantled with snow and detritus— large dolerite boulders and small shale flakes—but each hill display columnar joint-planes over some portion of its frontage. At one plac (Hill 620) the dolerite cliffs recede in a crescent and take on the appearanc of corrie-walls; along the cliff-foot lie quantities of pro-talus and scree but there is no development of a scoured rock-floor and the feature mus be considered no more than an embryo corrie (cf. Thompson, 1950, p. 151) While frost-action is the first agent to come to mind in explaining the for mation of the cliffs, the proximity of many of the cliffs to the sea and thei elevations with respect to the raised beaches, strongly suggest that wave work may have taken a prominent part in steepening them. Both fros and waves were probably involved in most cases.

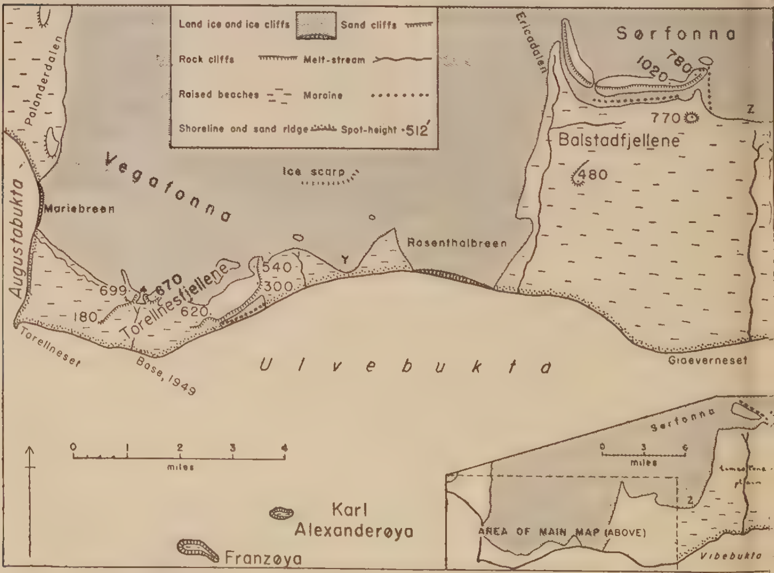


Fig. 3. Landforms of south-western Nordaustlandet. Data from surveys by the Oxford University Expeditions of 1949 and 1951. The place names 'Torellnesfjellene' and 'Balstadfjellene' are provisional only

Very clearly marked, though shallow, depressions occur on the inland flanks of Hills 1020–780 and 620–540. Although they are very probably related in origin to the basins found near the snouts of many glaciers, these basins are peculiar because both occur on high ground and not in valleys. The seaward edge of each is marked by an upstanding rim, along which dolerite outcrops are frequently seen. Such rims—found on several other hills also—are occasionally sharp enough to recall arêtes. If they are not connected with glacial scour of the basins behind, they may well be entirely attributed to frost-action.

Separating the two groups of hills and partially concealed by ice, is a valley which leads north-westwards, under the name of Ericadalen (Fig. 3), to Palanderbukta (a southern arm of Wahlenbergfjorden. Fig. 1). Rock outcrops have been observed at several points along the flanking glacier-cap margins and it appears that the valley marks one of the few lines of dissection of the interior plateau (Glen, 1941*a*, p. 76). There seems to be a similar valley immediately to the east of 'Balstadfjellene', which is at present occupied by ice-lobe Z. Palanderdalen, to the west of Vegafonna (see Fig. 3), is the third major valley of the region.

East of ice-lobe Z, and lying between the raised beaches and the main body of Sørfonna, is a gently undulating plain, the surface of which consists of frost-shattered limestone débris, dissected by snow-lined stream-channels and marked by occasional small lakes. The area's seaward margin is a low scarp or ridge which increases in altitude and prominence eastwards. At the inland edge stands a higher scarp, studded with moraines and marking the present limit of the ice and also of the main interior plateau. The plain is thus comparable in position and in elevation with the intermediate erosion-surface farther west.

No jagged nunataks occur in southern Nordaustlandet, though a few rounded, featureless patches of bare ground protrude through the thin margins of the glacier-caps. The patches consist entirely of boulders, shale flakes and mud: no rock was ever found *in situ*.

6. WEATHERING AND GLACIAL DEPOSITS

(a) **Rock-decay and frost-heaving.** One of the most striking characteristics of southern Nordaustlandet is the uneven progress of weathering between the hilltops and the intervening lowlands. The summits of all the hills are strewn with fields of dolerite boulders derived for the most part from the subjacent bedrock. While many of the boulders are sub-angular and have evidently been split by frost-action in the past, almost all of them are oxidised to a depth of several inches and some display spheroidal weathering. Lichens are generally abundant and moss and other types of tundra vegetation grow thickly in places. These conditions prevail up to the very edge of the glacier-caps.

In contrast, the boulders of the lower land, often arranged in lines and steps, as described in the section on raised beaches (p. 298), are oxidised to a depth of only a fraction of an inch, show no signs of spheroidal weathering and are markedly free of lichens and mosses. Many of these water-rounded boulders have been cleft by recent frost-shattering. The frequency with which such contrasts between hills and valleys are observed makes it certain that the former have been free of ice for a long time, whereas recession from the latter has been much more recent.

Apart from forming vast boulder-fields, the weathering of dolerite has also given rise to a small 'tor' (Hill 540) and to fine columnar joint-plane cliffs. Most of the cliff-faces are weathered to a degree intermediate between those of the hilltops and of the lowlands. No spheroidal weathering was observed, but the cliffs are largely free from signs of recent frost-shattering.

Much less massive than the dolerite, the Triassic shales display a quite different kind of weathering. Large boulders are never seen. Almost all the frost-shattered shale takes the form of small flakes which often occur in large fields. In these instances the flakes have evidently been derived by frost-shattering and frost-heaving from the bedrock below. The surface of such 'edge-wise conglomerate' usually has a reticulated aspect: polygons are marked out by flakes standing on edge, whereas the slightly lower centres are characterised by flat-lying débris. The abundance of lichens and even flowering plants in most cases suggests that no recent heaving movement has occurred, despite the proximity of the permafrost zone to the surface; but in one place polygons were found on a high raised beach.

Where edgewise conglomerate extends down the side of a hill, the polygonal pattern is replaced to some extent by stone stripes, in which lines of flakes stand on edge, oriented in the direction of slope and movement. Examples of the work of frost-heaving also include mud-polygons, large 'boils' rising above the local surface, and rectangular patches of fresh mud and pebbles amidst others of much more weathered aspect. Large boulders as foci for surrounding rings of vertical flakes were noted on several occasions.

(b) **Moraines and associated features.** The total absence of striations and *roches moutonnées* is remarkable. It appears that, despite the proximity and greater former extent of the glacier-caps, weathering has been effective in destroying such traces of glacial scour as may once have existed.

Still more impressive is the poor development of end-moraines. Only two short strips of moraine occur beside Vegafonna (Fig. 3). One lies high up on the ice-edge between Hills 699 and 670. It consists very largely of shale flakes, sand and silt, and appears to contain a considerable mass of ice. It may therefore have a similar origin to that of the dirt cones described in the next section. The second moraine lies along the base of an ice-field fringing the eastern part of 'Torellnesfjellene'. It is composed almost entirely of angular dolerite boulders and lies on a raised beach some 50 ft. above sea level. The boulders *may* represent an accumulation of scree which has rolled down from the crags above, but the arrangement of the detritus and the whole character of the ridge suggest most strongly that the feature is a true moraine. This in turn implies that the ice-field is in fact a relic of a former extension of Vegafonna (which now terminates half a mile to the north). That this assumption is correct is borne out by Koldewey's map and text (1871).

In and to the east of 'Balstadfjellene' are three more moraines, fringing Sørfonna. The first stretches as a line of low piles across the ice-field veiling the southern face of Hills 1020 and 780. Sørfonna may formerly have been joined to this ice-field and the moraine is best regarded as having been glacially transported. It is conceivable that the débris, which consists of shale flakes, together with many small particles of dolerite, may have resulted from the action of frost-heaving and solifluction on ice-shrouded bedrock immediately uphill. Certainly the moraine cannot be ordinary frost-shattered scree, for most of the *exposed* rock above is dolerite.

The second moraine of the eastern group extends as a straggling line of shale piles along the west flank of ice-lobe Z. It is thus a lateral moraine, deriving its material from Hill 780, where several exposures of Trias occur. There is no comparable lateral moraine on the other side of this lobe; nor is any well-developed end-moraine visible. The explanation for such an anomaly must lie in the strictly localised source of débris. The third moraine of the group lies still farther east, behind the limestone plain mentioned in the previous section. The cones here are up to 30 ft. in height, but it is doubtful if they are kames, as the débris is reported to have the characteristics of till rather than those of washed material.

As recorded earlier, some of the boulder-fields associated with raised-beach steps may have originated as moraines. A few lines of cliff-foot débris, other than those just considered, may also be in part morainic. The same may conceivably be true of three small hills which were observed, but not visited, on the south-eastern flank of Vegafonna. However, the total volume of material involved in all the moraines and pseudo-moraines is remarkably small, and the observer is left with the strong impression that, in general, the local glacier-caps are merely covering their respective plateaux; that they are accomplishing little erosion except where the ice passes over or beside cliffs and hills.

Although boulder clay, in the strict sense, was never observed, the strip of saturated clay, silt and pebbles, lining much of the ice-edge in the low-lying areas, was probably ground-moraine. No sorting or stratification was discovered and the chief constituent seemed to be clay derived from the local shales. No outwash fans were seen, but it may be, as was suggested earlier, that much of the raised-beach shingle and sand is no more than wave-worked outwash. Certainly, sources of similar limestone and chert are available under the northern part of Vegafonna. Much of the débris of the deltas is also 'secondary' outwash.

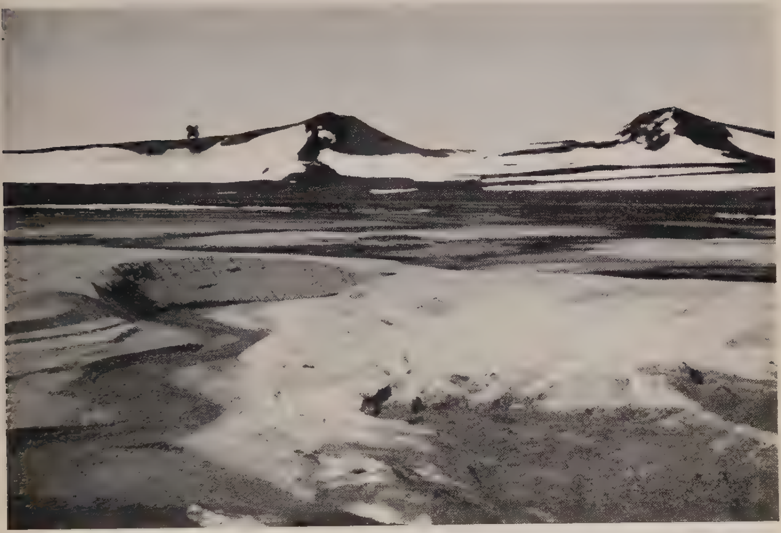
No undoubted drumlins, eskers, kames, kame-terraces or glacial-lake deposits were seen; a fact which serves to re-emphasise the general poverty of glacial erosion and deposition.

7. ICE-FEATURES

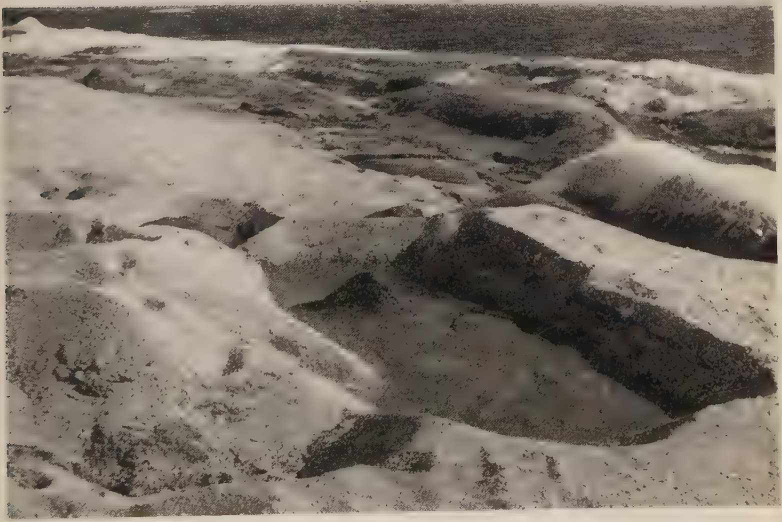
The area investigated is bounded by ice throughout its inland margin (Figs. 1 and 3). The dominant ice-features are two glacier-caps—Vegafonna and Sørfonna—which reach altitudes of 1400 ft. and 2200 ft., respectively. If Ahlmann's suggestion (1933–4) that a subglacial plateau occurs at 1200–1350 ft. is valid in this region, it follows that Vegafonna must be a very thin shroud, whereas Sørfonna may attain a maximum thickness of 1000 ft. Certainly, Vegafonna appears to lie on a highland mass separating Ericadalen from Palanderdalen; while Sørfonna undoubtedly owes its existence to a ridge of high land between Wahlenbergfjorden and Vibebukta (Fig. 1).

In plan, Vegafonna is roughly circular, in the form of Ahlmann's ideal glacier-cap (Ahlmann, 1948, p. 60). Its margin is somewhat irregular, in that several lobes of ice have taken advantage of subglacial depressions to push outwards to the sea. Mariebreen and Rosenthalbreen, whose sea-cliffs were discussed earlier, are examples of such lobes. They are little crevassed and bear almost no resemblance to 'normal' valley-glaciers. Indeed, Rosenthalbreen is separated from Vegafonna by a low ice divide and is probably destined to become a tiny glacier-cap itself. That Rosenthalbreen, Mariebreen and other lobes of Vegafonna are of comparatively recent formation is indicated by their extension across raised beaches. There appears to have been no great disturbance of the beach-deposits and it may well be that their outward encroachment—whether individual or as part of a general ice-advance—was gradual, and contemporaneous with the emergence of the land.

Sørfonna is joined to Vegafonna by a thin layer of ice in Ericadalen. Sørfonna's elongated plan stands in strong contrast to that of Vegafonna, but it seems likely that further thinning of the former would sever the western part from the eastern, creating a smaller but distinct glacier-cap from the present mere tributary of Austfonna (Fig. 1). Sørfonna sends out a number of lobes to the sea in Wahlenbergfjorden, but on the south coast the only prominent lobe is that marked Z. The ice here is very thin and its



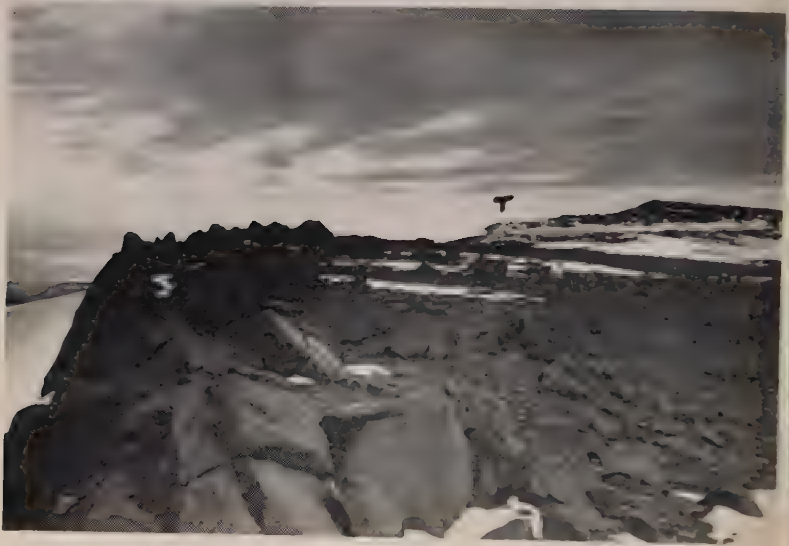
A. Hills 699 and 670 and strandflat from base camp



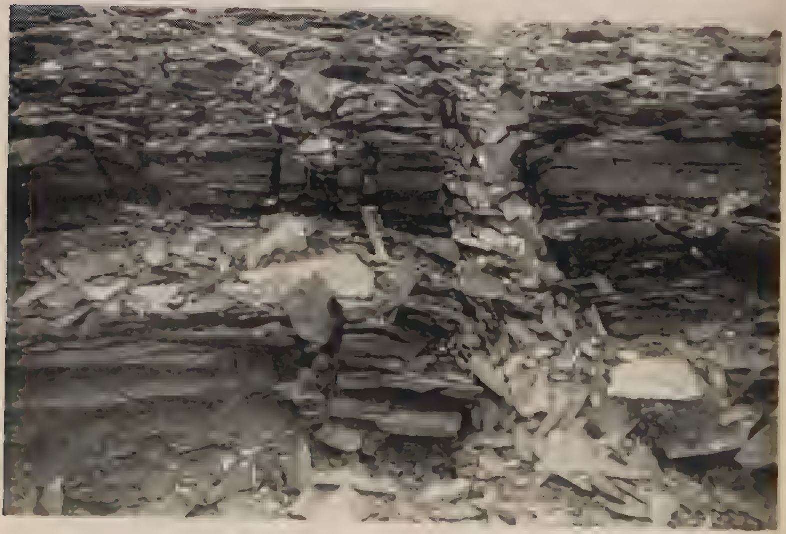
B. Shoreline sand-ridge with core of stranded floes bearing dirt-cones and kettle-holes

SOUTHERN NORDAUSTLANDET (NORTH-EAST LAND), SPITSBERGEN

[*To face p.* 306.



A. Hills 750 (left foreground) and 1020 (right background) looking WSW



B. Frost-shattered fossiliferous black shales near Hill 540

SOUTHERN NORDAUSTLANDET (NORTH-EAST LAND), SPITSBERGEN

To face p. 307].

large crystals and saturated cavities proclaim an advanced state of wastage. That this lobe also has developed during the postglacial emergence of Nordaustlandet is implied by its transgression of the higher raised beaches.

In section, both glacier-caps display smooth domed profiles. Although the slopes appear steep to men hauling sledges, they seldom exceed10°. A measurement of 4°, on the south flank of Vegafonna, is probably close to the average. Along almost its entire front, the ice thins quite gradually towards the sea, feathering out as an unspectacular and débris-free carapace (Sandford, 1929, pp. 457–8).

Although the flanks of both glacier-caps were found to lie below the firn-line, a cover of snow up to four feet thick remained in place throughout the summer of 1949. Some melting took place occasionally, giving rise to small rivulets and wet sledging surfaces, but compared with the conditions experienced by a former expedition (Sandford, 1929, p. 465), we found a very cool summer. The fact that several blue ice-bands were observed in the snow-cover of each pit excavated, suggests that the amount of melting must have been small for more than one year. On the other hand, the total precipitation of one inch during the four summer weeks of 1949 (21 July to 17 August), is a reminder that the positive régime of the Nordaustlandet glacier-caps rests on a very precarious balance of accumulation (Glen, 1941*a*, pp. 145–6).

Previous remarks concerning fluctuations in the position of the ice-edge must now be summarised. From observations made in 1949 it is quite clear that the hilltops have been deglacierised for a much longer period than the intervening valleys. The relation of some of the glacier-cap lobes to the raised beaches demonstrates the occurrence of fairly recent ice-advances, though most of the lobes are now showing signs of passivity or decay. A comparison of the 1949 maps and observations with those of Koldewey (1871) reveals a retreat of half a mile in the front of Mariebreen, during the last eighty years. A similar comparison makes it certain that a recession of about half a mile has taken place between Hills 620 and 540 in 'Torellnesfjellene', over the same period. A separation of ice-lobe Y from Rosenthalbreen has likewise occurred. The balance of evidence indicates that the ice of southern Nordaustlandet is currently in a state of slow retreat and thinning, even though the continued existence of sea-cliffs truncating some of the lobes implies that slow outward motion continues.

The problem of how Bråsvellbreen (Fig. 1) developed in the space of two years (1936–8) was investigated by the 1949 Oxford Expedition and by its successor in 1951. Since the glacier is to be the subject of a separate paper, no discussion of the matter will be undertaken here. But it would be misleading to omit mention of this tremendous outward surge of ice, not far to the east of an area of predominant recession.

In addition to the 'ice-scarp' discussed earlier, certain other ice-features should be recorded. The ice-fields fronting Hills 620–540 and Hills 1020–780 are probably relics of former extensions of the glacier-caps. Some structural details may be observed, for each terminates in a steep cliff at its eastern end. Stratification planes intersected by curved thrust-planes may be discerned in the upper parts of each, suggesting a period of snow accumulation on top of the relict ice; each snow-stratum is coated with dust (presumably wind-blown) and it is these 'dirt-bands' which make the structures so clear. The coating of ice and snow with débris takes another form. Small dirt-cones are frequently observed on stranded ice-floes along the shore and on the ice-fields inland. The origin of such features by a process of inversion of relief has been treated by Swithinbank (1950).

8. KARL ALEXANDERØYA

In the preceding sections reference has occasionally been made to Karl Alexanderøya, which lies three miles offshore from 'Torellnesfjellene'. The 1949 expedition made the first recorded landing on the island, though its dolerite-cliffs have long been known (Sandford, 1926, p. 650).

The island measures half a mile from east to west and a quarter of a mile from north to south. Two thirds of its circumference is bounded by steep sea-cliffs, 100 to 150 ft. high, but in the north-west and especially in the east there are low ridges of coarse débris along the shore, backed by limited and steeply rising series of raised beaches. Beaches occur right to the summit plateau of the island (200 ft.) and consist almost entirely of rounded limestone and chert pebbles similar to those found on the mainland. No local source was found and it must be assumed that the pebbles were transported to the island during a phase of marine transgression or when the Nordaustlandet ice-front reached this point, or both.

The dolerite is exposed over large areas, forming low flat-topped ridges above the beaches. It is oxidised to a very limited degree and shows excellent rounding which, because of the lack of striations, the proximity of raised beaches and the strong development of joint-plane erosion, must be ascribed to marine action. Recent frost-shattering is remarkable for its absence; nor, indeed, are there any permanent snow- or ice-fields. Vegetation cover is limited mainly to lichens and a few mosses, growing in places sheltered from the prevailing north-westerly winds.

The dolerite displays columnar joint-planes and the island has all the characteristics of an intrusion, including two *in situ* patches of 'baked' sedimentary rock on its upper surface. Comparatively deep water extends in all directions. Sandford's theory (1926, p. 655) that Karl Alexanderøya, among other islands, may be a horst-remnant of the sunken mass which formerly covered southern Hinlopenstretet, is thus tentatively confirmed. It remains uncertain whether the island is part of a sill or of a large vertical intrusion. In either case the angular pattern of dolerite ridges on the summit plateau may well represent later discordant intrusions (Sandford, personal communication).

9. SUMMARY AND CONCLUSIONS

(1) Triassic shale outcrops not only in 'Torellnesfjellene', but also in 'Balstadfjellene': its margin must, therefore, be placed a few miles farther east than heretofore. Morainic piles of shale also suggest a greater northward extension.

(2) Carbo-Permian limestone crops out 6¼ miles to the east of the easternmost Trias. The boundary between the two systems may therefore lie along the depression occupied by ice-lobe Z.

(3) Dolerite is extensively exposed in association with the Trias. Columnar jointing, geomorphological relations and the discovery of 'baked' contact-rocks and a chilled zone on its upper margin, demonstrate that the mainland dolerite occurs as one or more sills.

(4) Evidence that Karl Alexanderøya—visited for the first time in 1949—and probably Franzøya, are dolerite intrusions, lends support to Sandford's theory that the numerous islands of southern Hinlopenstretet are horst relics.

(5) A ridge of sand and shingle which forms most of the shore has been built up by waves, stranding ice-floes and bergs, expansion and contraction of 'fast ice', and the engulfment of grounded floes by blown sand.

(6) The drift of beach-material appears to be in the direction of the longshore current and contrary to that of the strong and dominant northwest wind.

(7) Raised beaches were observed at altitudes up to 350 ft. in the west and over 400 ft. in the east. No major stillstand levels occur and no warping of the beaches is recorded. The material involved was partly imported by beach-drifting, but much of it may be reworked outwash. There is no reason to believe that the emergence of Nordaustlandet has ceased.

(8) Dissection of the beaches by melt-streams is in the initial stage. The greatest destruction occurs close to the ice-edge, where the drainage is least organised.

(9) Most of the lakes on the raised beaches originated as lagoons ponded by the shoreline sand-ridge. A few may be kettles.

(10) The two groups of hills are remnants of an erosion-surface intermediate between the strandflat and the main interior plateau. They are almost entirely composed of resistant dolerite and display fine cliffs, some of which were partly formed by wave-action at higher sea levels. Corries, so abundant elsewhere in Spitsbergen, are here conspicuous by their absence.

(11) Most of the features commonly associated with frost-action are present, including shattered boulders, flakes, edgewise conglomerate, scree, polygons, stone-stripes, 'boils' and a permafrost layer close to the surface. Bedrock, boulders and flakes are much more deeply weathered on the hill-tops than in the valleys, indicating an earlier recession of the ice from the former.

(12) *Roches moutonnées* and striations are absent. Even moraines are poorly developed. A thin strip of clayey and silty till is exposed along the margin of the ice. Little contemporary outwash is visible; nor are drumlins, eskers, kames, kame-terraces or glacial-lake deposits to be seen. The ice itself is notably free from supraglacial and englacial débris.

(13) The two domed glacier-caps are of uncertain thickness. Both have sent out projecting lobes towards the sea and, though the outward flow continues, there is a general tendency towards stagnation and decay. Three small-scale withdrawals of the ice-front since 1868 are demonstrable; in these cases, and also elsewhere, the ice originally advanced over raised beaches.

(14) Meteorological and glaciological evidence strongly suggests that the summer of 1949 was cooler than others of which there are records.

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EXPLANATION OF PLATES

PLATE 12

A. Hills 699 and 670 from base camp; remnants of dolerite sill(s) and of the intermediate erosion-surface. Exposure of black shale at X. Middleground comprises boulder-fields, raised beaches and initial stream-valleys of the strandflat. In foreground is the shoreline sand-ridge, here 7 ft. high: bedded in places but often having a core of stranded floes.

B. Shoreline sand-ridge, showing core of stranded floes, on which dirt-cones and kettle-holes are forming. The remains of the winter bay-ice (middleground) disappeared a few days later, together with their coating of sand and silt blown from the raised beaches. On the horizon lies Karl Alexanderøya (dolerite).

PLATE 13

A. Hills 780 (left foreground) and 1020 (right background), looking WSW. Dolerite 'rim' formation resulting from differential frost-shattering and glacial scour. Slight oxidation of dolerite. Rich moss and lichen development in nooks sheltered from NW. winds. Triassic shales outcrop at T. Ice-field veils steep southern face of hills (left).

B. Triassic exposure immediately north of Hill 540. Fossiliferous black fissile shales and mudstones: one horizon calcareous. Dip 10° SW. Differential frost-shattering well shown: similar débris forms extensive fields of 'edgewise conglomerate'. The hammer is 12 inches long.

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Postscript. TRIASSIC ROCKS IN SOUTHERN NORDAUSTLANDET (NORTH-EAST LAND).

The occurrence of Triassic rocks at Torellneset arises from a statement by De Geer (*Mission suédoise pour la mésure d'un arc de méridien au Spitzberg*: ii, pt. 9, *Topographie et Géologie*. Stockholm, 1923, 25 pp.), who had established a section of Triassic and Jurassic sediments at Thumb Point (Tumlingodden) on Wilhelmøya, south of Torellneset, on the west side of Hinlopenstretet.

Mr. Thompson's specimens collected *in situ* are, essentially, thin-bedded buff to grey sandstones and chert at the eastern end of 'Balstadfjellene', abundant black shales from 'Torellnesfjellene', and dolerites. Little could be done with the sedimentary rocks, although a few imprints of lamellibranchs occur, until a collection made bed by bed by Mr. Michael Holland at Thumb Point in 1951 became available. The proofs of this paper arrived in Oxford at the moment when Mr. Holland was unpacking his collection, and he has allowed the writer, on behalf of Mr. Thompson, who is now abroad, to compare the material.

It is evident that the buff and grey sandstones of 'Balstadfjellene', which occur also in the lower part of 'Torellnesfjellene', can be matched lithologically with those in the higher part of the Upper Trias of Thumb Point, above a dolerite sill there; the black shales of 'Torellnesfjellene' are lithologically similar to those at the top of the section at Thumb Point, above a second sill, which are Jurassic—Frebold (*Skrift. Svalbard Ishavet*, No. 31, 1930, p. 59) has identified them as Lower Kimmeridgian.

No comparable black shales occur at lower (Triassic) horizons at Thumb Point, and it arises therefore that Mr. Thompson's black 'Triassic' shales of 'Torellnesfjellene' are, on lithological evidence, Jurassic, with Upper Trias below them there and occurring in the eastern part of 'Balstadfjellene'. The only fossils found in them are poorly preserved but suggest *Holobia*, which, being Triassic, is at variance with the stratigraphical evidence. Jurassic rocks are therefore postulated but not proved in Nordaustlandet thanks to Mr. Thompson's work. It is noteworthy that the buff Upper Triassic sediments, with *Nathorstites* sp. and *Posidonia* sp. cf. *P. mimeo* Öberg, occur at the greatest altitude in the east and the black shales succeed them westward in the evident general direction of dip. I am indebted to Mr. J. M. Edmonds for determining the fossils.

K. S. SANDFORD.

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